Weeds

VOLUME 7
JANUARY 1959
NUMBER 1

Journal of the Weed Society of America

Weeds

Issued Quarterly by the Weed Society of America

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WEEDS is a quarterly journal published by the Weed Society of America. Editorial offices are located at the University of Wisconsin, Madison, Wisconsin. Printing is by the W. F. Humphrey Press Inc., Geneva, New York. Subscription price is $6.00 yearly for four issues: single copies $1.50. Address all communications regarding subscriptions, advertising and reprints to W. C. Jacob. Department of Agronomy, University of Illinois, Urbana, Illinois. Inquiries concerning information on manuscripts and other material for publication should be addressed to the Editorial Offices. All checks, money orders and other remittances should be made payable to the Weed Society of America.

Entered as second-class matter at the post office at Urbana, Illinois with additional entry at Geneva, New York.

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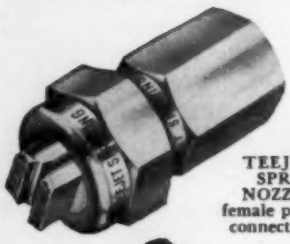

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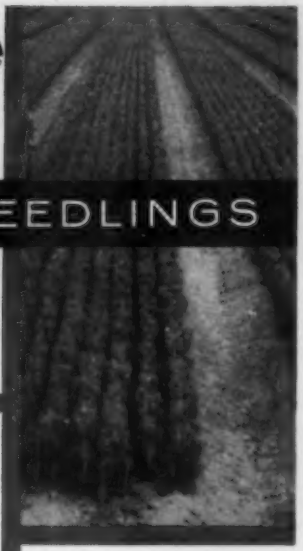

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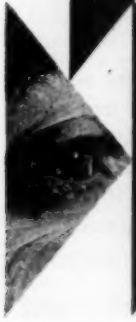

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JOURNAL OF THE WEED SOCIETY OF AMERICA

VOLUME 7 JANUARY 1959 NUMBER 1

The Effects of Quackgrass on Germination and Seedling Development of Certain Crop Plants[1]

THOR KOMMEDAHL, J. B. KOTHEIMER, and J. V. BERNARDINI[2]

INTRODUCTION

Most of the evidence for the production of toxic substances, by one plant, that affect the growth and survival of another, is circumstantial, according to a review by Bonner (5). There is direct evidence that the leaves of *Artemisia absinthium* L. (3), *Encelia farinosa* A. Gray (6), and *Thamnosma montana* Torr. & Frem. (2), produce substances which are toxic to other plants. A substance has been isolated from the roots of guayule which is toxic to guayule but which is unimportant agriculturally because this substance remains only a short time in the soil (4). Also dead brome grass roots have been found to be toxic to brome seedlings (1); however the evidence here is indirect (5). Le Tourneau et al. (13) have shown also that water extracts from tissues of many crops and weeds inhibit germination of wheat.

Quackgrass (*Agropyron repens* (L.) Beauv.) has been reported to have a deleterious effect on other weeds (7), small grains (8, 11, 14), grasses (15), and legumes (9, 12). Many farmers have found it difficult to establish a stand of alfalfa on newly-plowed sod of quackgrass. While several explanations are possible for the adverse effects of quackgrass on other plants, it is possible that toxic substances are produced by the rhizomes of quackgrass. Experiments were made to explore the possibility that substances could be produced by living and dead rhizomes that would inhibit the growth of alfalfa, small grains, and flax.

MATERIALS AND METHODS

For field tests, comparisons were made with two adjacent plots, one of which was previously infested with quackgrass and one previously not infested. Quackgrass sod was first broken up with a rotary

[1]Paper No. 3910, Scientific Journal Series, Minnesota Agricultural Experiment Station.

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tiller. This was followed by raking and hand-picking of rhizomes. Rhizomes that were missed by this method were weeded out when shoots of quackgrass emerged during the course of the experiment. The adjacent non-infested plot was prepared in the same way and in both plots seeds, or grains, of five crops were sown in June, immediately following removal of rhizomes from infested plots. Crops were planted in rows 4 feet long, with 100 seeds per row.

Soil and pots used in greenhouse tests were autoclaved for 2 hours. All clay pots used were 4 inches in diameter. The soil used, whether autoclaved or not, was a mixture of two parts silt loam to one part sand.

All materials that were ground, whether leaves or rhizomes, were ground to a number 40 mesh size in a Wiley mill. The rhizomes were collected from a field of quackgrass in the fall, were washed, dipped in one percent NaOCl and dried prior to being ground. For the experiments done on the effects on wheat, the rhizomes were dried in an air-circulated electric oven at 60° C for 6 hours. The oven-dried rhizomes proved to be gummy and hard to grind; therefore in the remaining experiments the rhizomes were air-dried which eliminated the gumminess and facilitated grinding.

In some experiments ground rhizomes were dampened and autoclaved at 121° C for 90 minutes on 2 successive days. Plating tests showed these autoclaved rhizomes to be sterile. In certain other tests, the ground rhizomes were autoclaved for 20 to 30 minutes, which was sufficient to kill plant pathogens but not spore-forming bacteria.

Ground rhizomes were added to soil of clay pots in different amounts, from 5 to 20 gm per pot. Five gm of ground rhizomes per pot is approximately one percent, by weight, of the soil; 10 gm is two percent; 15 gm is three percent; and 20 gm is four percent. It was determined that in nature rhizomes make up 0.6 to 1 percent, by weight, of soil. The ground material was always added to each pot separately.

The laboratory tests for germination of alfalfa and wheat were made in deep Petri plates each fitted with three sheets of filter paper. For tests with alfalfa, 9 ml of either distilled water or extract were added to each plate; 16 plates of 25 seeds per plate were always used per treatment. For tests with wheat, 12 ml of either distilled water or extract were added to each plate and 10 plates of 10 grains per plate were used per treatment. Germination tests were done in a Mangelsdorf Germinator set at 20° C. Observations were made after 3 days for alfalfa and after 4 or 5 days for wheat.

The only disinfectant used was a one percent solution of NaOCl.

Departures from and additional details for these methods are so indicated in the appropriate section on experimental results.

RESULTS

Field test.

Tests were made in the field to get evidence for farmers' claims that it was difficult to establish stands of alfalfa on newly-plowed

quackgrass-infested soil, and, that some crops sometimes fared poorly on newly-plowed quackgrass sod. Thus alfalfa, flax, barley, wheat, and oats were sown on two plots in the field, one previously infested and one previously not infested with quackgrass rhizomes. Attempts were made to remove rhizomes from the infested plots, prior to planting, to avoid active competition from live quackgrass. The results are in Table 1, and are averages of two varieties of alfalfa, and three varieties per crop of flax, barley, oats, and wheat, with three replicates per variety in a split-plot design. Some of these data have been reported previously (9).

Table 1. The effect of previously-infested quackgrass soil in the field on stand and dry weight per plant of five crops harvested 3 months from sowing.

Crop	Dry wt/plant, in gm		Stand on infested soil as percent of control
	Infested soil	Non-infested soil	
Alfalfa	0.2	0.5	56
Flax	0.2	2.0	81
Barley	1.1	4.2	52
Oats	1.8	4.1	76
Wheat	1.6	3.9	66

The two alfalfa varieties, Ranger and Narragansett, averaged nearly twice the stand and over twice the dry weight per plant on land previously non-infested compared to the previously infested plots.

The stand of barley varieties, Kindred, Montcalm, and Peatland was about twice that on previously non-infested land with dry weights per plant four times as much. Lee, Mida, and Selkirk wheat varieties were not affected as much as the barley varieties. The reduction in stand and dry weight on infested land for the oat varieties Ajax, Bonda, and Rodney were similar to those for wheat. Relatively poor stands were obtained for flax; however, the dry weights per plant of the three varieties, B5128, Marine, and Redwood averaged 10 times more for plants grown on non-infested land.

Greenhouse and laboratory tests.

ALFALFA. *Effects of ground rhizomes in soil.* Seeds of Ranger alfalfa were sown in clay pots containing autoclaved soil, with 20 seeds per pot. In a second set, seeds were sown in autoclaved soil mixed with 10 and 15 gm of autoclaved ground rhizomes per pot. After 7 days, 66 percent of the seeds in pots with 10 gm, and 58 percent of seeds in pots with 15 gm of rhizomes germinated, compared with 81 percent that germinated in the controls. In addition, the first leaf beyond the cotyledons was fully developed, at 7 days, and the epicotyl up to the first true leaf was 1 to 3 cm long in the controls; however the first true leaf was undeveloped and the epicotyl was less than 1 cm long in pots containing ground rhizomes.

In Table 2 are the results from a similar experiment where ground rhizomes were added to soil. Fresh and dry weights of 1-

Table 2. The effect of ground rhizomes of quackgrass in soil on the percentage stand, fresh weight, and dry weight of Ranger alfalfa sown in clay pots in the greenhouse.[a]

Ground rhizomes per pot, in gm	Alfalfa weight, mg per plant		Percentage alfalfa stand after 1 month
	Fresh	Dry	
0	219	37	35
10	162	21	36
20	120	17	36

[a]Based on averages of 5 pots, 100 seeds per pot.

month-old alfalfa plants were reduced but stands were the same as in the controls (stand is expressed as the percentage of seeds sown per pot).

Effects of rhizome filtrates in soil on growth. To ascertain the effects of leachates or filtrates from quackgrass rhizomes on the growth of alfalfa, rhizomes were air-dried and ground. Then 200 gm of ground material were mixed with 1 L of distilled water, autoclaved for 20 minutes, allowed to steep for 24 hours, and filtered through a Buchner funnel. Water to make 10 L was added to the filtrate, reautoclaved, and a portion of this was used daily to water potted alfalfa seedlings. The residue from the filtration was dried in a gas oven for 72 hours at 90–110° C, reautoclaved, and added to autoclaved soil. Ground rhizomes and leached ground rhizome residue were added to soil in amounts of 15 gm/pot. The results are in Figure 1 and Table 3.

Table 3. The effect on stand and dry weight of the addition of ground rhizomes, leached rhizomes, and filtrates from ground rhizomes of quackgrass on Ranger alfalfa sown in soil.[a]

Material added to soil	Percentage alfalfa stand	Dry weight alfalfa per plant in mg
None (control)	75	118
Ground rhizomes	73	41
Leached ground rhizome residue	72	16
Water filtrate	70	48

[a]Data are based on averages of 5 pots per treatment, 25 seeds per pot, on 6-week-old plants and the stand is expressed as the percentage of seeds sown per pot.

None of the treatments affected the stand of 6-week-old plants, but plant dry weight was less than half that of the control where either ground rhizomes were added or where the filtrate from rhizomes was applied daily to soil. The greatest suppression of growth occurred in pots where the residue obtained after filtration was added to soil (Figure 1).

Extraction apparently was not complete and the residue might still contain a substantial amount of one or more toxic substances.

To test this hypothesis, 80 gm of autoclaved residue were re-suspended in 400 ml of distilled water for 1 hour, filtered and the

Figure 1. The effect of quackgrass on germination and growth of alfalfa. *Left:* The effect of a filtrate from ground rhizomes on germination of alfalfa seed after 3 days (upper row) compared to controls (lower row) in tests made in Petri plates. *Right:* The pot on the left is the control, the middle pot was watered daily with a water extract made from ground rhizomes and the pot on the right contains alfalfa growing in soil mixed with leached, ground-rhizome residue. Soil, ground-rhizome residue, and filtrate were autoclaved prior to sowing alfalfa. All plants in the three pots were 6 weeks old.

filtrate made up to 10 L and autoclaved. Twenty-five seeds of Ranger alfalfa were sown in each of 20 pots containing autoclaved soil. Ten pots were watered daily with the filtrate and 10 with tap water. After 5 weeks the shoots were harvested and weighed. The plants growing in the filtrate-watered pots averaged 0.16 gm per plant while the controls averaged 0.22 gm per plant—a difference in weight of 27 percent.

Effects of filtrates on germination in Petri plates. Two kinds of tests for germination were made in Petri plates. In one, 80 gm of autoclaved, freshly-ground rhizomes were suspended in 400 ml of distilled water. In a second 80 gm of the autoclaved rhizome residue from a previous filtration (described in the preceding section) were re-suspended in 400 ml of distilled water. Both suspensions were allowed to steep for 1 hour, filtered, and dispensed immediately into Petri plates in which alfalfa seeds were immediately sown. Percentage germination and seedling length were determined. Seedling length was measured from root tip to the cotyledonary node.

The filtrates from freshly-ground rhizomes delayed germination of alfalfa and stunted the seedlings that eventually appeared (Figure 1). After 1 day the percentage germination was 0.05 for seeds germinating in the filtrate and 41.6 for those in distilled water. After 3 days the germination percentages were 73.6 for treated and 79.6 for control plates. However the seedling length averaged 11.4 mm in

plates with the filtrate and 24.2 mm in control plates. Thus seeds germinating in filtrates germinated more slowly and grew 47 percent less than the controls.

Similar results were obtained with the filtrate made from the residue of a previous filtration. The germination percentages after 3 days were 72.8 for treated and 74.0 for control plates. However, the seedling length averaged 11.9 mm in plates with the filtrate and 26.0 mm in control plates. As before, the principal effect was in stunting seedling growth. Moreover the extraction from the residue used in the experiments summarized in Table 3 was apparently not complete and the activity of filtrates made from this residue was as great as filtrates from freshly-ground rhizomes, with respect to its effect on alfalfa seedlings.

WHEAT AND OATS. *Effect on growth in soil previously occupied by live quackgrass.* Quackgrass was allowed to grow for 3 months in flats in the greenhouse after which roots and rhizomes were sifted out. Half of this soil was autoclaved and three flats for each of four treatments were used to determine the effects from soil previously in quackgrass on growth of Selkirk wheat and Bonda oats. The plants were dried in an air-circulated electric oven at 60° C for 10 hours and the average dry weight per plant was determined. The results are in Table 4.

Wheat and oat seedlings in quackgrass soil were shorter and of lower dry weight than were seedlings from soil not previously in quackgrass. Autoclaving the soil had no apparent effect probably

Table 4. The growth of 3-week-old wheat and oat seedlings on soil previously infested with quackgrass in the greenhouse for a 3-month period.

Crop	Observation[a]	Infested soil		Non-infested soil	
		Autoclaved	Non-autoclaved	Autoclaved	Non-autoclaved
Wheat	Height, cm	16.5	16.4	21.2	22.1
	Dry weight, mg	1.9	2.2	3.9	4.1
Oats	Height, cm	16.3	16.8	19.2	19.2
	Dry weight, mg	2.2	2.1	3.1	3.7

[a]Based on averages of plants in 3 flats per treatment, 100 plants per flat, and expressed as averages per plant.

because such soil rapidly became recolonized with microorganisms. Also the nonautoclaved soil may have contained few pathogenic organisms. The growing of quackgrass would obviously result in less fertile soil, thus additional experiments were done by using ground rhizomes and by using extracts to possibly evaluate this as a factor.

Effects on germination in soil containing ground rhizomes. Different amounts of autoclaved and nonautoclaved ground rhizomes were added to autoclaved and nonautoclaved soil, respectively, and 20 grains of wheat were sown in each of three or five replicate pots of soil per treatment. The ground rhizomes were autoclaved for 90 minutes on 2 successive days. The number of seedlings were counted

and the height estimated after 7 days. The results are summarized in Table 5.

Table 5. Stand at 7 days in the greenhouse of Selkirk wheat seedlings in autoclaved and nonautoclaved soil containing different amounts of autoclaved and nonautoclaved ground rhizomes of quackgrass respectively.

Treatment of soils and rhizomes	Ground rhizomes per pot, in gm	Wheat stand, in percent[a]		Estimated height of wheat, as percent of control
		Trial 1	Trial 2	Trial 1
Autoclaved	0	86	72	100
	5	71	—	70
	10	65	73	80
	15	35	—	50
	20	—	42	—
Nonautoclaved	0	71	—	—
	20	4	—	—

[a]Percentages are averages of three or five pots per treatment, 20 grains of wheat per pot. Trials 1 and 2 were done at different times. Stand is based on percentage of grains planted per pot.

The addition of nonautoclaved rhizomes to nonautoclaved soil gave very low seedling stands while reduction in stand was not as great where autoclaved soil was used. Moreover the reduction in stand was temporary on autoclaved soil containing autoclaved rhizomes. Ungerminated grains in nonautoclaved rhizome soils were decayed whereas many grains of the controls had germinated but had not yet appeared above the soil surface at 7 days. Possibly rhizomes had predisposed wheat grains to decay by microorganisms from the nonautoclaved soil or had increased the activity of microorganisms in the nonautoclaved soil so that decomposition of organic matter, including wheat grains, could be increased.

Effect on germination in soil containing leachate from live quackgrass. Leachates from growing quackgrass were tested for their effects on germination of wheat. To do this, six heavily-potbound quackgrass plants having thick rhizomes were washed and immersed in NaOCl and transplanted to autoclaved quartz sand in 1 quart porcelain crocks. These crocks had been treated previously with NaOCl and were filled with sand that had been autoclaved for 3 hours. Twenty-five 1-month-old seedlings of Bonda oats were transplanted to each of six crocks. A third set of six crocks served as controls and contained no plants. To each crock was added 250 ml of water but no nutrients. Plants grew for 1 or 2 weeks in the crocks during which time the water levels were kept constant, then the water was decanted, filtered, autoclaved, and poured onto autoclaved soil in clay pots. In some tests, this leachate was concentrated in a glass still to half its volume and this concentrated solution was added to Petri plates (Figure 2). Wheat grains were tested for germination in plates containing solutions of each concentration. Leachate collected after 1 week was added in 150 ml amounts to each of 10 pots and sown to wheat, with 15 grains per pot. Leachate collected after 2 weeks was added in 125 ml amounts to each of two pots per treatment and sown

Figure 2. The effects of leachate from growing quackgrass on germination of wheat grains after 4 days in Petri plates. Note the slower germination rate in the upper row of five seedlings compared with the controls in the lower row.

to wheat, with 25 grains per pot. Notes were taken after 3 weeks for each test. The results with the 2-week collection of leachate are summarized in Table 6.

Table 6. Effect on stand of Selkirk wheat in soil to which had been added leachate from quartz sand previously occupied by growing quackgrass or oats.

Leachate[a]	pH	Percentage wheat stand at intervals after sowing[b]		
		7 days	14 days	21 days
Control	6.5	86	92	92
Oats	6.5	72	90	90
Quackgrass	6.9	2	18	26

[a]Leachate was the constant volume of water maintained in each crock after 2 weeks' growth of quackgrass or oats in sand. Control leachate was obtained from crocks in which no plants had been growing.

[b]Stand is based on percentage of grains planted per pot, 2 pots per treatment of 25 grains per pot.

Stands in soil watered with leachate of quackgrass was very low after 7 days and was only 25 percent after 3 weeks compared to 92 percent for controls. Leachates from oat soil had no effect after 2 weeks and little effect even initially.

In a set of pots not included in Table 6, grains of wheat were unearthed after 1, 2, and 3 weeks from sowing. The majority of grains that had not emerged were found to have germinated to the extent that roots were produced; however plumules were lacking (Figure 3). On the other hand, grains unearthed in the controls had plumules averaging about 4 mm in length.

Where leachate from 1-week-old transplants of quackgrass was added to pots subsequently sown to wheat, shoots were cut 3 weeks after sowing and weighed immediately. There was no effect of this

Figure 3. The effect of leachate from growing quackgrass on germination of wheat grains in soil. Note the absence of a plumule in one of the grains that failed to emerge above soil level.

less-concentrated leachate on germination after 3 weeks (81 percent compared to 79 percent for controls); and the fresh weight for treated plants averaged only 0.05 gm per plant less on soil plus leachate than on control soils.

The effects of tissue extracts on germination. Green leaves of 6-week-old Selkirk wheat, and, leaves and rhizomes of quackgrass were washed and surface-disinfected, then each of these materials was oven-dried and ground. Five gm of each material were added to 150 ml of distilled water and autoclaved for 1 hour. After cooling for 3 hours, the solutions were filtered and autoclaved for another hour. These water extracts were dispensed into Petri plates to determine their effects on germination of wheat. The results are in Table 7.

Quackgrass and wheat leaf extracts were more deleterious to germination and growth than were quackgrass rhizome extracts. However greater amounts of water were used to obtain leachates from growing rhizomes and therefore they were less concentrated than leaf extracts. In attempts to approximate equal concentrations, 500 ml of the leachate from the 2-week-old sand culture were concentrated to half the original volume in a glass still. The resulting 250

ml were filtered, autoclaved and dispensed into Petri plates. These results are also in Table 7.

Leachates from living rhizomes in sand culture were most harmful to secondary roots of wheat at both concentrations in that none

Table 7. The effects on germination of wheat of extracts from tissues of quackgrass and wheat leaves, quackgrass rhizomes, and of two concentrations of leachates from sand-culture solution from quackgrass rhizomes.

Extract	pH	Percentage germination	Length, in cm[a]		Root growth
			Roots	Shoots	
Quackgrass leaves	5.8	45	1.0	0.5–3.0	Shriveled; few secondary roots
Wheat leaves	7.0	43	1.0–3.0	2.5–5.0	Vigorous; most with secondary roots
Quackgrass rhizomes	4.8	63	1.0–2.5	1.5–3.5	Shriveled; most with secondary roots
Sand-culture leachate[b]	8.0	59	2.0–4.5	1.0–3.0	No secondary roots; first leaf slightly chlorotic
Water (control)	7.2	81	6.0–10.0	4.0–6.0	Normal; secondary roots forming
Conc. sand culture leachate[c]	8.2	55	1.0	0.5–2.0	Shriveled; no secondary roots
Water (control)	7.2	80	3.0–6.0	2.0	Normal; secondary roots forming

[a]Measurements and observations were made after 5 days for all except tests with concentrated leachate and its control, where they were made at 4 days.
[b]Two weeks' accumulation of leachate.
[c]Two weeks' accumulation of leachate but concentrated to half that of original.

developed. Extracts from wheat leaves were about as toxic to wheat as were those from quackgrass leaves with respect to percentage germination and length of root and coleoptile. However secondary root development was much less in wheat treated with extracts from quackgrass leaves. The differences given in Table 7 might be attributed to differences in pH; however, in other tests with water adjusted to different pH units, no difference in growth of wheat seedlings was found from pH 4.0 to 9.0, and inhibition in growth did not appear until pH 10.5.

DISCUSSION

Stunting and chlorosis were observed in crop seedlings growing in any of the following situations: in the field in soil previously occupied by living quackgrass, in the greenhouse in which ground rhizomes had been added to soil in clay pots, in soil in which water extracts or filtrates of ground or live rhizomes were added, and in Petri plates containing water extracts from ground and living rhizomes. It was demonstrated also that a deleterious substance was present in leaves as well as rhizomes, and it has been reported previously (9) that even germinating grains of quackgrass apparently produce a toxic substance.

Whenever autoclaved soil and rhizomes were used, germination of seedlings was lower initially; later the stands were about equal to those of the controls. However, when non-sterile soil and rhizomes were used the initially lower stands were usually permanent. This was attributed principally to pathogens that caused blighted seedlings. Such organisms come from either the soil or from rhizomes (9, 10). The inability to establish stands of alfalfa on quackgrass sod in Minnesota may be the result of toxic substances from the quackgrass or predisposition to seedling blight, or both. In addition, substances from quackgrass may affect soil microflora, and thus indirectly affect growth of plants. The variable results with nonautoclaved soil with respect to numbers of diseased plants may be attributed to differences in populations of soil-borne pathogens, between different lots of nonautoclaved soil.

While the wide C:N ratio may be a factor in both field and greenhouse tests where rhizomes were present in soil, this factor was at least reduced, if not eliminated, where water extracts of rhizomes were used in Petri plates. It is possible also that autoclaving the extracts could alter toxicity although this has not been clearly established in our tests. In some parts of the United States, the use of autoclaved soil is in itself toxic to seedlings; however, in all the work done with Minnesota soils, this has not been found to be so and is discounted as a factor in the work reported here.

It was apparent also that the deleterious substances were resistant to heating, and may be only partially water soluble, as reported by LeTourneau and Heggeness (12). On the other hand, extraction of toxic substances from rhizomes may not have been complete, or more than one toxic substance may have been present in rhizomes.

SUMMARY

Stands and dry weights per plant were less on soil previously infested with quackgrass compared to soil not previously in quackgrass, when alfalfa, flax, wheat, oats and barley were sown in field plots.

Fresh and dry weights of alfalfa were less when ground rhizomes of quackgrass, or water extracts of ground rhizomes were added to soil, in tests made in the greenhouse. Also, the addition of rhizome extracts to Petri plates resulted in inhibition in growth of alfalfa seedlings. Even when ground rhizomes were leached in water, dried, and leached again, the second leachate inhibited growth of alfalfa in plate tests, and the residue from the first leaching inhibited growth when mixed with soil subsequently sown to alfalfa.

Wheat and oat seedlings grew less on quackgrass soil in greenhouse as well as in field tests. The addition to soil of extracts from ground rhizomes of quackgrass inhibited growth of wheat seedlings but did not alter the number of plants that germinated, provided autoclaved soil was used. Where nonautoclaved soil was used, fewer plants grew and those were stunted in their growth in the presence of ground rhizome extracts.

Leachate from growing quackgrass was added to soil in which wheat grains were sown, and this resulted in lower stands and less

growth than occurred when leachate from oat soils or tap water was added to soil. Sometimes germinating wheat grains produced roots but no plumules when leachate from quackgrass was added to soil.

Water extracts from leaves as well as from rhizomes of quackgrass were inhibitory to growth of wheat seedlings.

The over-all deleterious effect of the quackgrass plants or their products upon the crop plants tested may be due to a combination of toxic compounds produced by the quackgrass, which injured the crop plants, and invasion of the crop plants by soil microorganisms. There seems little doubt, however, that living quackgrass plants, and the residues from the dead ones, rather severely injure germinating seeds and young seedlings of the crop plants tested. This may well explain the difficulty of obtaining good stands of some crop plants on land previously infested with quackgrass. Quackgrass therefore is a noxious weed not only in its competition with crop plants for nutrients, water, and light; it also makes the soil it inhabits unfavorable for some crop plants, when it is growing, and its injurious effects persist for some time after its death.

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The Seasonal Development of Johnson Grass Plants[1]

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JOHNSON grass *(Sorghum halepense* L., Pers.) is a native of the Mediterranean coastal countries and was introduced into the United States about 1830 by Governor Means of South Carolina (5). About ten years later some seed was planted in fertile river bottom soil near Selma, Alabama, by Colonel William Johnson. As Colonel Johnson was the first person to cultivate the grass extensively in the United States, it was named for him. Since that time, the grass has been intentionally cultivated and unintentionally disseminated in many areas of this country. A recent distribution map by Hitchcock (3) shows that the plant may be found in all but about a dozen northern states.

Each mature plant may produce large numbers of seeds which are of major importance in the spread of the weed. The seeds are borne in large, open panicles in spikelets which shatter readily when mature. Johnson grass seed is commonly disseminated by floods, birds, cattle, and the sale of unclean agricultural seed and remains viable after passage through the digestive tract of animals (1). Once established, the weed persists because of the seed production and also through rhizomes. These rhizomes are usually large and fleshy in appearance and have pronounced scale leaves at the nodes. Vegetative shoots may be produced from axillary or terminal buds on the rhizomes, thus initiating new plants.

The successful control of most weeds, whether annual or perennial, is dependent upon treatment at some critical stage in the life cycle. With this precept in mind, it was thought advisable to study systematically the seasonal development of Johnson grass. Therefore, the morphological development of both seedlings and plants developing from old rhizomes was followed under Indiana conditions.

THE DEVELOPMENT OF JOHNSON GRASS PLANTS FROM SEED

The plants observed in this investigation were started in the greenhouse in the spring of 1951 from seed collected the preceding fall in the Ohio River bottoms near Rockport, Indiana. After the seed had germinated and the seedlings were in the three- to five-leaf stage, they were transplanted to a nursery, and representative plants were collected and photographed at various stages of growth. Since rhizome development seemed to be more closely correlated with top growth than with time from seeding, the growth stage was used as the more reliable criterion of relative plant age.

The initiation of rhizomes on seedling plants was first noted when

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plants were in the seven-leaf stage (about 50 days after planting). One to several rhizomes were produced from axillary buds at the base of the stem. A moderate amount of rhizome development was observed when the plants were in the boot stage (about 66 days after planting); small rhizome branches had developed from axillary buds on the oldest rhizomes as shown in Figure 1. This is in contrast to the reports of workers in Alabama (4) and Texas (2) who did not observe rhizome formation until the plants had headed or flowered. Numerous observations indicate that there is no apparent relationship between the position of the node at the base of the stem and the direction in which the rhizome will grow from it.

Figure 1. Development of rhizomes, crown, and tillers on a Johnson grass seedling in the boot stage. The two dates refer to the time of seeding and collecting.

The total growth of rhizomes increased greatly from the time the plant was in the boot stage until the seedheads expanded and the seed was in the dough stage. The extensive growth of rhizomes shown in Figure 2 was observed on a typical plant at the time the seed was in the dough stage. The increased growth of rhizomes during the period from boot stage to dough stage may be seen clearly by comparing Figure 2 with Figure 1.

In order to determine more quantitatively the relationship between the development of the tops and rhizomes of seedling plants, weekly collections of five plants were made beginning at the time the plants were in the boot stage and continuing through the remainder of the growing season. The dry weight of both tops and rhizomes was determined and the results are shown in Figure 3. The dry weight of the

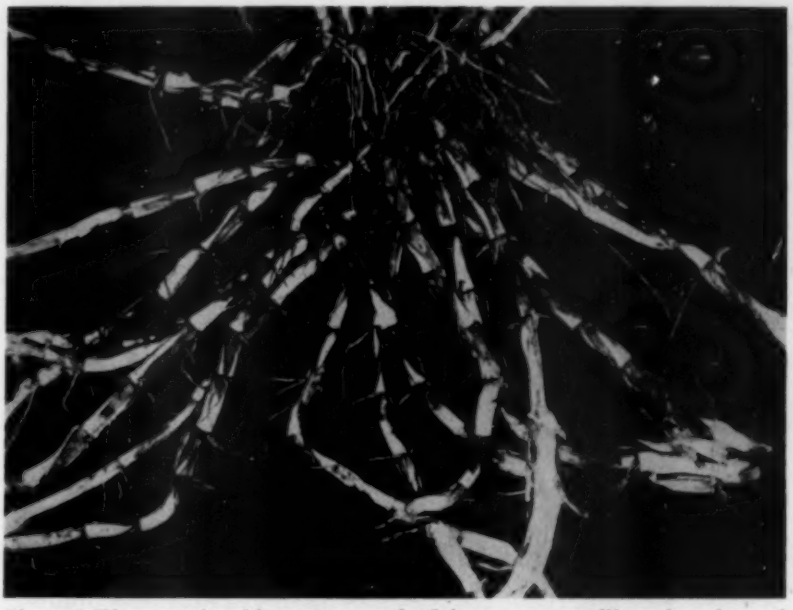

Figure 2. The extensive rhizome system of a Johnson grass seedling when the seed of the plant was in the dough stage. Collection made Aug. 16.

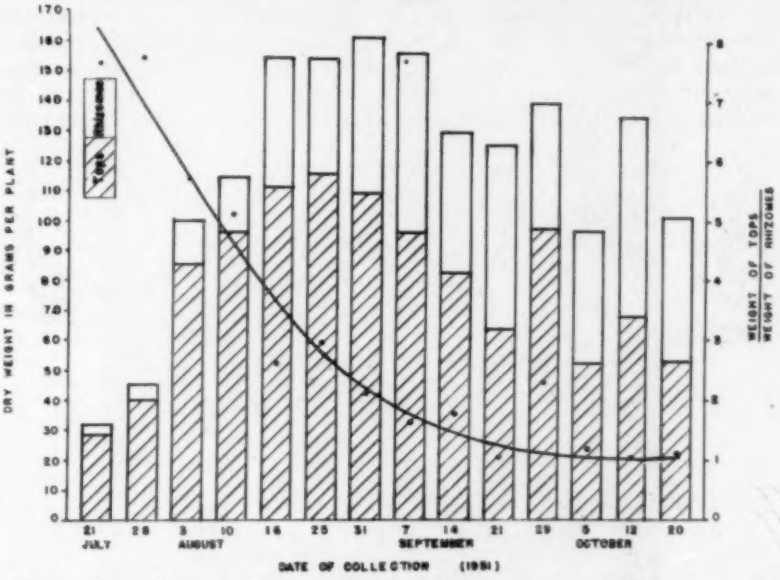

Figure 3. Dry weight of tops and rhizomes of Johnson grass seedlings over a 14 week collection period. Each bar represents the average of five plants. The top/rhizome ratio is represented by the dots and curve superimposed upon the bars.

tops reached a maximum value when the most mature seeds were in the dough stage. After this time, the dry weight of the tops decreased gradually until the end of the growing season. This loss in weight may be attributed to loss of lower leaves, loss of seed due to shattering, and translocation of carbohydrates from the tops to the rhizomes. The weight of the rhizomes increased steadily and reached a near maximum value when the seeds were beginning to mature (September 7). From this date until the end of the growing season, there was no consistent increase in the weight of the rhizomes although the tops remained green and presumably continued to produce carbohydrates. These data are in general agreement with the observations of Sturkie (4). It is interesting to note the decline in the top/rhizome ratio from the beginning of the collecting period. The ratio was above 7.5 for the first two collections and decreased to about 3.0 at the time of maximum top growth on August 25. This indicates that even though the weight of the tops was increasing from July 21 to August 25, the weight of the rhizomes was increasing at a more rapid rate. The ratio continued to decline after the August 25th collection and approached unity at the end of the collection period.

THE DEVELOPMENT OF JOHNSON GRASS PLANTS FROM RHIZOMES

Under Indiana conditions, the seasonal development of Johnson grass plants from rhizomes is similar to that of plants developing from seed. Growth of the rhizomes in the spring may originate from the axillary or apical buds of the rhizomes which were produced the preceding year. Upon reaching the soil level, these new rhizomes become aerial stems and produce crowns and tillers. Rhizomes may arise from these crowns somewhat earlier than they do from the crowns of seedling plants. The drawing in Figure 4 was made from

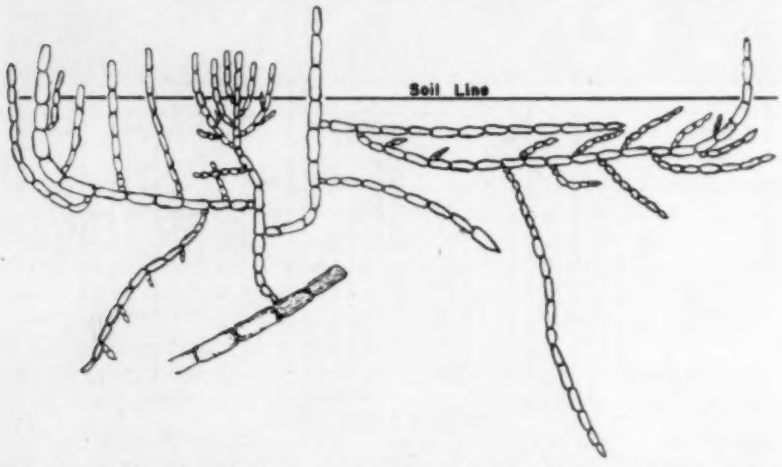

Figure 4. The rhizome system of a mature plant which developed from one axillary bud on an old rhizome. The old rhizome is shaded.

a mature plant collected in August. This entire mass of rhizomes and the aerial stems which were produced above the soil level originated from an axillary bud on an old rhizome (shaded) in a period of approximately 4 months. Such extensive development from a single bud illustrates the importance of obtaining a complete kill of all rhizomes in the soil before control of Johnson grass can be attained.

THE DEVELOPMENT OF RHIZOMES FROM BURIED CROWNS OF SEEDLINGS

A number of seedlings which were grown in flats in the greenhouse were not transplanted to the nursery until late June or early July. Upon transplanting, the crowns of a number of these seedlings were placed 6 inches below the soil level. Tops were not removed. The underground growth which resulted from this type of transplanting is shown in Figure 5. This photograph taken August 14 shows a

Figure 5. Rhizomes and elongated internodes formed on a seedling by placing the crown below the soil level upon transplanting.

plant in which four rhizomes were produced from the axillary buds at the original crown. The internode between the fourth and fifth nodes had apparently elongated and another crown had been formed at the soil level. The crown of the plant is characterized by the formation of adventitious (or crown) roots from nodes at or near the soil surface.

A number of plants which had developed similarly to the one shown in Figure 5 were transplanted again after the rhizomes were separated from the aerial portion of the plants by cutting the stems near the center of the elongated internode. These plants were transplanted on August 14 with their crowns placed 6 inches below the soil surface. Tops were not removed. The plants were then collected on September 12 and examined. Rhizomes were produced from the buried crown of the plants in less than 1 month. Another crown had been formed, making a total of three successive crowns and two groups of rhizomes formed on one plant by placing the crowns below the soil surface when transplanting. Although burying the crowns of these young seedlings had no appreciable effect on the time required for rhizome formation or the number of rhizomes formed, it did result in slower development of the tops (as compared with normally transplanted seedlings). The control plants were always taller and their seedheads developed more rapidly than did those on the buried plants.

DISCUSSION

The results of this study indicate that, under Indiana conditions, seedling Johnson grass plants should be controlled sometime before rhizomes are formed; i.e., before the seven-leaf stage. It apparently is not sufficient merely to cover the crowns of seedling plants with soil during cultivation, as new crowns may be formed. It is possible that complete covering of very young plants could result in adequate control. This is a common cultural practice for control of young annual plants of similar size. Suitable herbicides could play an important part at this growth stage; either as a pre-emergence measure or by contact killing before the critical seven-leaf stage is reached.

Once the rhizomes have been formed, the problem of control is multiplied many times over, as each axillary bud apparently is capable of giving rise to a new plant. The total weight of rhizomes formed from only one buried rhizome bud indicates that killing of tops, either by clipping or contact chemicals, after the first rhizomes have formed has very little value as a control measure. If a chemical is to be useful as a systemic herbicide for Johnson grass control over large areas it must be translocated into all of the rhizome buds and must inhibit further growth of these buds.

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A Study of the Absorption and Translocation of Several Chemicals in Johnson Grass, and an Evaluation of Their Effectiveness for Its Control under Field Conditions[1]

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JOHNSON grass (*Sorghum halepense* L.) is one of the most troublesome weeds in the United States. Since its introduction into the Southeast in 1830, this weed has spread to a total of 38 states. The perennial habit of Johnson grass contributes to its widespread geographical distribution and enables it to survive moderately severe winters. In addition to fleshy rhizomes, Johnson grass is usually a prolific producer of viable seed which may give rise to reinfestations after the established plants are controlled.

Extensive research on Johnson grass control has been conducted, utilizing both cultural and chemical procedures. Cultural methods, while effective for Johnson grass control under certain conditions, are usually laborious and expensive and often necessitate the removal of cropland from cultivation during the treatment period. Many herbicides have been tested in previous years, but most of these have proved too expensive for general use on low-value land.

More recently, the sodium salt of 2,2–dichloropropionic acid (referred to hereafter as dalapon)[3] has shown excellent promise for Johnson grass control (2, 4, 5, 6, 7, 8, 9). This chemical and other compounds have been tested extensively during the past several years in areas where Johnson grass is a major weed problem. The responses of Johnson grass to dalapon and other herbicides have varied with the environmental conditions encountered. The experiments described here were designed to evaluate absorption, translocation, and field performance of certain herbicides under conditions typical of the southeastern Piedmont Plateau.

MATERIALS AND METHODS

Greenhouse absorption studies.

Johnson grass plants were established in 4-inch pots by planting one to three rhizome segments (each consisting of two nodes and the connecting internode) in each pot of Cecil loam soil. Usually two or three plants per pot were retained for treatment; however, the number varied from one to five, depending on the number of emerged plants. The herbicidal sprays were applied to first growth, or the plants were clipped and the vigorous regrowth was treated. In all penetration and absorption studies Johnson grass plants which

[1]Cooperative investigations of the Crops Research Division, ARS, USDA, and the Georgia Experiment Station. Journal Series No. 325, Georgia Experiment Station, Experiment, Georgia.

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[3]Acre rates of dalapon are expressed as pounds of the sodium salt in all experiments. The final spray solutions, unless otherwise stated, contained 0.5 percent, by volume, of surfactant (sodium heptadecyl sulfate).

varied in height from 8 to 15 inches were sprayed with various rates of dalapon in a spray volume of 35 gal/A utilizing calibrated greenhouse equipment which simulated field application. Treatment by dipping was not used since preliminary data indicated that herbicide residues could not be washed effectively from dipped foliage.

Before the spraying process, the soil in each pot was covered with absorbent paper or vermiculite to prevent contact between the herbicide and soil. After spraying, the soil was uncovered and the plants in each test were immediately exposed to one of several variables described below. At the end of the exposure period the herbicide residues were removed by inverting the pots and agitating the plants in two containers of warm (approx. 100° F) water containing respectively approximately 0.1 and 0.05 percent surfactant (sodium lauryl sulfate) and then rinsed in a container of clear water. Finally the plants were gently rinsed in warm running tap water. A similar procedure was used in previous studies to remove 2,4–D from bean and corn plants (3). In preliminary tests a treated check was sprayed and washed immediately to determine the adequacy of residue removal.

On the day of spraying and either 2, 3, or 4 weeks later, according to the growth rate, height measurements to the tip of the longest leaf were made on each plant. The data presented are the average differences between these two measurements. The growth which occurred after treatment was assumed to be inversely proportional to the penetration and absorption of the herbicide. The method was not designed to evaluate critically micro-differences in absorption, but rather to measure gross absorption responses of sufficient magnitude to affect plant growth over a period of time. Adsorption cannot be definitely separated from absorption by the methods used. From a practical viewpoint, the herbicide not removed by this washing technique probably would not be removed from Johnson grass plants under field conditions by rainfall occurring after treatment.

Split-plot or randomized block experiments with three to fifteen replicates were used. In all tests an effort was made to group uniform plants into each replicate before the treatments were applied in order to reduce initial variation within a replicate.

In some experiments, especially where the plants had been growing in pots for a considerable period before treatment, new shoots arose from the Johnson grass crowns in some pots. These young shoots were clipped back as needed in order that final height measurements be made only of plants designated for testing.

In a test designed to evaluate the effect of pH on absorption, values of pH 4.5, 6.5, and 9.0 were developed for the dalapon spray solutions by adding Coleman pH buffer tablets to the final spray mixtures. The pH values were checked on a Beckman glass electrode pH meter. A surfactant was not added to the herbicidal solutions used in this experiment. The sprays were applied and the herbicidal residue removed after a 1-hour exposure.

To develop a temperature differential, one lot of plants, immediately after spraying, was exposed for 1 hour to an average tempera-

ture of 60° F in an incubator while the remaining plants were exposed to a temperature of 78° F under average greenhouse conditions. Since each pot was placed into and removed from the incubator one at a time, necessitating frequent opening of the unit, there was a slight range of temperatures during the exposure interval, especially during the beginning or near the end of the one hour period, but the average exposure during the one hour after spraying was 60° F.

In an experiment designed to evaluate the effect of a prior dark period on absorption, one half of the Johnson grass plants were placed in darkness under a large cardboard box for 48 hours prior to spraying while the remaining plants were placed in sunlight on the same greenhouse bench. Average air temperature readings in the light were 2.7° F higher than under the box. One half of each group of plants was sprayed with dalapon at 15 lb/A and exposed to the residues 1 hour. The other plants were untreated.

Greenhouse translocation studies.

Johnson grass plants were established by planting several rhizome segments in 7-inch pots containing Cecil loam soil and allowing the plants to grow for several months after emergence. When the plants reached a height of 30 to 36 inches, they were clipped back as needed to approximately 3 to 5 inches but were allowed to regrow to a height of 12 to 18 inches before treatment. The method of spray applications was the same as for the absorption tests described above. A surfactant (sodium heptadecyl sulfate) was used in all spray solutions at a concentration of 0.5 percent. The following chemicals at indicated acre rates were used: dalapon at 15 lb; sodium salt of 2,2,3–trichloropropionic acid (2,2,3–TPA) at 15 lb; 3–amino–1,2,4–triazole (amitrol) at 2 lb; a mixture of dalapon at 15 lb and amitrol at 2 lb; and 4–chlorophenoxyacetic acid (4–CPA) at 20 lb.[4] Randomized block or split plot tests with four replications were used.

To develop a soil moisture differential, one group of plants was placed on a dry bench and watered only when the plants showed extreme moisture stress. Another group of plants received subirrigation continuously. The low moisture series was exposed to stress conditions for 4 weeks before and 2 weeks after treatment. A reduced sunlight level was developed by inserting half of the test plants in a cage covered with a triple layer of cheesecloth for a period of 2 weeks before and continuously after treatment. The other plants were exposed to average greenhouse conditions. Weston light readings made semi-daily showed a reduction of 60 percent in light intensity under the cloth. Air and soil temperatures were reduced on the average 2.5° and 1.8° F respectively under the cloth. In the surfactant experiment, one-half of the pots were sprayed with herbicidal solutions containing 0.5 percent of sodium heptadecyl sulfate, while other pots received herbicidal sprays without the addition of a surfactant.

[4]Acre rates of all compounds except 4–CPA expressed as pounds of active ingredient. Rates of 4–CPA refer to pounds of acid equivalent per acre.

In a preliminary test (Table 1) the effects of time on translocation were studied by spraying Johnson grass plants with various herbicides and then, after either 1 or 4 weeks, removing the rhizomes from the parent plants, cutting them into segments of two nodes and an internode, and planting the segments in flats of Cecil soil to observe and measure the average height of new shoots. The relative amount of translocation that occurred during the 1 or 4 week periods after treatment was assumed to be inversely proportional to average shoot height for any treatment in comparison with the untreated check. Other data, not reported here, included growth of parent plants after treatment and the total percent sprouting of rhizome segments. Similar data were obtained from the other translocation tests.

Field evaluation trials, noncropped areas.

Field applications of herbicides were made in an acreage volume of 35 to 70 gallons of water which contained 0.5 percent of added surfactant (sodium heptadecyl sulfate) unless otherwise specified. The sprays were applied with calibrated equipment in April or May on Johnson grass which ranged in height from 12 to 24 inches. Repeated applications of certain chemicals were made 7 to 10 days after initial spraying.

Randomized block experiments with three replicates were used. The plot size was 6 x 15 feet in 1956, and 8 x 10 feet in 1957. Earlier tests have been reported previously (4, 5). The 1956 test was located on land which had been cultivated for several years while the 1957 test area contained an old established stand. The soil in the 1957 area had not been cultivated for at least 20 years, but the Johnson grass usually had been clipped or burned annually.

In 1956, the following compounds at indicated acre rates were used: dalapon in single applications of 5, 10, and 20 lbs; dalapon in two applications spaced 7 to 10 days apart as follows: 2.5 + 2.5; 5 + 5; 2.5 + 5.0; and 5.0 + 2.5 pounds; and 2,3,6–trichlorobenzoic acid (2,3,6–TBA) at 30 pounds.[5] In 1957, dalapon was used at the following rates: 5 + 5; 10; 15; 20; and 30 pounds.

All data were collected by counting plants at ground level in a square yard near the center of each plot.

Field evaluation trials, preplanting treatments.

The following cultural procedure was used in conjunction with herbicidal treatment of Johnson grass at Experiment (Cecil clay loam soil), and Plains (Greenville clay loam soil) in 1955–1957: (1) the land was plowed in late fall or early spring; (2) after the Johnson grass reached a height of 8 to 12 inches in early spring the soil was thoroughly disked; (3) herbicidal sprays were applied when the Johnson grass re-emerged to a height of 12 to 24 inches; (4) the Johnson grass received another thorough disking either 1, 2, 3, or 4 weeks after herbicidal treatment; and (5) crops were planted 0, 1, 2,

[5]Acre rate of 2,3,6–TBA expressed as pounds of acid equivalent. This formulation was 80 percent 2,3,6–TBA, supplied by the American Chemical Paint Company.

and 4 weeks after disking, according to the test involved. Observations were made throughout the season of herbicidal effects on Johnson grass and the respective crops.

In 1955 the following herbicides and acre rates were applied at Plains, Georgia, on April 22: dalapon at 10, 15, and 20 pounds; amitrol at 4 pounds; dalapon at 10 + amitrol at 2 pounds; 2,2,3–TPA at 10 and 20 pounds; and 2,2,3–TPA at 10 + amitrol at 2 pounds. The same herbicides were applied at Experiment, Georgia, on May 12, except that 4–CPA at 20 lb/A was substituted for 2,2,3–TPA at 10 pounds. In 1956, the following chemicals were used at Experiment, Georgia, on May 15: dalapon in 4 treatments of 5 lb/A initially then 5 additional pounds in either 10, 7, 4, or 2 days; dalapon in single dosages of 10, 15, or 20 pounds. At Plains, on June 20, the following chemicals were applied: dalapon at 10, 15, and 20 pounds, 2,3,6–TBA at 10 and 20 pounds. Preplanting trials at Experiment and Plains for 1957 were sprayed on May 29, and May 16 respectively with the following treatments: dalapon at 5, 10, 15 and 20 lb/A. All of the preplanting tests were randomized block or split-plot designs with three or four replicates. Plot size varied from 8 x 16 to 20 x 30 feet, according to the experiment involved. All sprays were applied with a calibrated plot sprayer (1), and all final spray solutions contained 0.5 percent of a surfactant (sodium heptadecyl sulfate) unless otherwise specified.

The time intervals between herbicidal applications and disking or planting (steps 4 and 5 outlined above) varied somewhat with each test, location, and year. In 1955, the soil was disked 4 weeks after herbicidal applications at Plains and 2 weeks after treatment at Experiment. Corn and cotton were planted 4 weeks after disking at Plains and 2 weeks after disking at Experiment. In the 1956 Experiment test, the whole plots were disked at 2, 3, or 4 weeks after spraying and corn, cotton, soybeans, and sorghum were planted in each whole plot 1 week after disking. In 1956, at Plains, the entire area was disked 7 days after spraying and corn, cotton, peanuts, and field peas were planted 14 days after disking. At Experiment, in 1957, disking was done either 1 or 2 weeks after herbicidal applications and corn was planted 0, 7, and 14 days after each disking, while at Plains the entire area was disked 2 weeks after spraying and corn was planted 2 weeks after disking.

In all pre-planting tests, counts of the Johnson grass stems at ground level were made in one or more square yard quadrats per plot or in 8 x 1 foot quadrats over the crop rows.

During 1955, rainfall was near normal at Plains (5.27 inches) and above normal at Experiment for 8 weeks after herbicidal applications (13.01 inches). Sporadically dry conditions prevailed at Experiment in 1956 (6.82 inches rain during first 8 weeks), while at Plains moisture was adequate for 8 weeks after spraying (6.82 inches). Rainfall in 1957 at Experiment for 8 weeks following herbicidal applications was normal (9.89 inches) but was below normal at Plains (4.91 inches).

RESULTS AND DISCUSSION

Greenhouse absorption studies.

The relative penetration and absorption of dalapon by Johnson grass plants as measured by growth responses that occurred after treatment, was determined in a preliminary experiment. The data for exposure intervals of 1, 15, 60 and 240 minutes after spraying are shown in Table 1. There was no significant reduction below an untreated check in growth of plants washed immediately after treatment (1 minute interval) indicating that the method used for removing the herbicide residues was satisfactory. Measurements made at both 2 and 4 weeks after treatment showed that the relative absorption of dalapon was most rapid during the first 60 minutes after application. There were no significant differences between exposure intervals of 60 and 240 minutes at either 2 or 4 weeks after treatment. Although absorption continued beyond 4 hours, the differences in growth between the 240 minute and 2 or 4 week exposures were not as great as between the 15 and 60 minute intervals. The overall effects of dalapon were somewhat more severe at the end of the 4-week interval than at 2 weeks. In subsequent tests final growth measurements were made at the end of 3 or 4 weeks depending on the rate of growth.

Table 1. Growth of Johnson grass foliage previously exposed for varying time intervals to dalapon sprayed at a rate of 15 lb/A.

Exposure interval minutes	Av. growth 2 and 4 weeks after treatment[a]			
	Two weeks		Four weeks	
	Inches	Percent of untreated check	Inches	Percent of untreated check
1[b]	5.4	100.0	6.1	82.2
15	3.9	72.0	3.3	44.6
60	1.8	33.3	1.3	17.6
240	2.1	38.8	1.5	20.3
Until measured (2 or 4 weeks)	1.3	24.1	0.1	1.4
Untreated check	5.4	—	7.4	100.0
LSD 5 pct level	2.8	—	1.8	—
LSD 1 pct level	N.S.	—	2.4	—

[a]The data are averages of four replicates.
[b]This series was washed immediately after the spraying procedure which lasted 45 to 60 sec.

In another experiment, absorption of dalapon at single or repeated dosages of 5 pounds and single dosages of 15 pounds for varying exposure intervals was studied (Table 2). There were no marked differences between the rates of dalapon or among exposure intervals of 1 hour, 24 hours, or 28 days.

The effect of pH levels of 4.5, 6.5, and 9.0 on absorption of dalapon at 15 lb/A is shown in Table 3. The data show an inverse relationship between the pH levels used and absorption of the herbicide. This factor could be of some importance in field applications of dalapon on Johnson grass.

Two experiments with six and 15 replicates respectively were con-

Table 2. Growth of Johnson grass foliage as affected by dalapon treatments at different levels, varying number of applications, and exposure intervals.

Rate lb/A	Number of treatments	Total applied lb/A	Exposure interval	Av. growth 4 wks. after initial treatment inches[a]	Percent of untreated check
5	1	5	1 hr	4.0	27.8
5	1	5	24 hr	2.9	20.1
5	1	5	28 da	2.1	14.6
5	2	10	1 hr	2.9	20.1
5	2	10	24 hr	2.3	16.0
5	2	10	28 da	2.1	14.6
15	1	15	1 hr	4.8	33.0
15	1	15	24 hr	3.9	27.0
15	1	15	28 da	3.4	23.6
15 (treated check)	1	15	1 min	13.4	93.0
Untreated check	—	—	—	14.4	100.0
LSD 5 pct level, treatment means				3.2	—
LSD 1 pct level, treatment means				4.4	—

[a]The data are averages of 3 replicates.

ducted to determine whether an 18° F differential (60–78°) during an exposure period of 1 hour to 15 lb/A of dalapon would result in detectable absorption differences. No significant differences occurred among plants exposed to 60° F or 78° F. This is not evidence, however, that another range or a wider temperature differential would not appreciably affect absorption of this compound.

Table 3. Effect of pH on penetration of dalapon at 15 lb/A into Johnson grass during a 1 hour exposure interval.

pH level	Average growth in inches 2 weeks after treatment[a]
4.5	2.3
6.5	12.6
9.0	19.5
LSD 5 pct level	5.4
LSD 1 pct level	7.3

[a]The data are averages of 15 replicates.

Two experiments were conducted to evaluate the effect of reduced sunlight on the subsequent absorption of dalapon. There were significant differences between the untreated checks and the sprayed plants and significant growth responses between plants exposed to 48 hours of darkness before treatment as opposed to plants left in sunlight. However, the treatment x light level interaction did not approach statistical significance at the 5 percent level which indicates that 48 hours total darkness before spraying had little effect on the penetration of dalapon. From the practical viewpoint this suggests that the activity of this herbicide under field conditions would not be appreciably reduced by brief periods of cloudy weather before treatments.

Greenhouse translocation studies.

Translocation of several herbicides from Johnson grass foliage to the rhizomes during 1 or 4 week intervals after spraying is shown by

the data in Table 4. Growth of rhizome shoots was significantly reduced following treatments of dalapon, amitrol, and a mixture of dalapon plus amitrol, but growth was not materially reduced fol-

Table 4. Apparent translocation of chemicals applied to Johnson grass foliage as measured by height of new shoots from rhizome segments.

Chemical	Rate lb/A	No. of rhizome segments planted[a]		Average height of rhizome shoots 3½ weeks after planting[b]			
		1 wk. interval	4 wk. interval	1 wk. interval		4 wk. interval	
				Inches	% of ck.	Inches	% of ck.
Dalapon	15	26	18	2.0	17.4	4.4	44.0
2,2,3–TPA	15	25	23	10.4	90.4	12.0	100.0
Amitrol	2	18	15	5.5	47.8	5.1	51.0
Dalapon + amitrol	15+2	12	22	1.0	8.7	5.2	52.0
4–CPA	20	30	15	10.4	90.4	10.0	100.0
Untreated check	—	26	16	11.5	—	10.0	—
LSD 5 pct level, height means				3.9	—	5.5	—
LSD 1 pct level, height means				5.4	—	N.S.	—

[a]Each rhizome segment consisted of two nodes and the connecting internode of rhizomes taken from four replicates, and each replicate consisted of one 7-inch pot containing at least one Johnson grass plant. The rhizomes were severed from the parent plants 1 or 4 weeks after spraying, cut into segments, and planted in flats of Cecil clay loam soil.

[b]Each figure is the average of all shoots that grew from all rhizome segments of plants that received a specified treatment.

lowing applications of 2,2,3–TPA and 4–CPA. There was a tendency for dalapon and a mixture of this material and amitrol to be more toxic when the rhizomes were removed from the parent plants 1 week after treatment than at 4 weeks. The effects of soil moisture levels and reduced sunlight on translocation of several herbicides are shown in Table 5. A reduced moisture level decreased apparent translocation of 2,2,3–TPA but had little effect on the movement of dalapon, amitrol, or 4–CPA. Translocation of amitrol was significantly reduced by decreased light but the effect on other herbicides was not great (Table 5). In another experiment, the addition of a surfactant did not affect appreciably translocation of dalapon.

Table 5. Effects of two levels of soil moisture and sunlight on translocation of herbicides in Johnson grass as measured by height of new shoots from rhizome segments[a].

Chemical	Rate lb/A	Av. ht. of rhizome shoots 4 weeks after planting[b]			
		Soil moisture test		Sunlight test	
		Wet soil inches	Dry soil inches	Sun inches	Shade inches
Dalapon	15	0.00	0.45	0.00	0.50
2,2,3–TPA	15	4.50	10.90	—	—
Amitrol	2	4.20	3.80	2.30	7.30
4–CPA	20	7.40	7.40	5.40	8.00
Untreated check	—	6.00	5.50	9.60	7.00
LSD 5 pct level		3.34	3.34	4.80	4.80
LSD 1 pct level		4.57	4.57	6.60	6.60

[a]Each rhizome segment consisted of two nodes and the connecting internode of rhizomes taken from four replicates, and each replicate consisted of one 7-inch pot containing at least one Johnson grass plant. The rhizomes were severed from the parent plants 2 weeks after spraying, cut into segments, and planted in flats of Cecil clay loam soil.

[b]Each figure is the average of all shoots that grew from all rhizome segments of plants that received a specified treatment.

Since a record was made of the position of each rhizome segment in the original rhizome planted, height data were available to correlate location of segments in a rhizome with translocation. There was no consistent indication that the chemicals used were concentrated in certain portions of the rhizomes. It should be noted, however, that although the rhizomes that developed under greenhouse conditions in the above tests seemed comparable in size to those which develop in Georgia Piedmont soil under field conditions, they were not as extensively developed as rhizomes observed in other geographical areas on more porous soils. Therefore, it is probable that the same degree of translocation would not be observed where the rhizome systems have developed more extensively.

Data in Tables 4 and 5, together with observations made during the period of these tests, indicate that dalapon was consistently the most effectively translocated chemical studied. Furthermore, the data indicated a trend toward greater dalapon toxicity in rhizomes removed from the sprayed plants at 2 weeks after treatment rather than at 1 or 4 weeks (Tables 4 and 5). These data formed a useful basis for the spacing of disking operations following field applications of herbicides for Johnson grass control in pre-planting experiments.

Field evaluation trials, noncropped areas.

Preliminary results on the effect of herbicides on Johnson grass control in noncropped Piedmont soil have been published previously (4, 5, 6). The data from experiments conducted in 1956 and 1957 are presented in Table 6. Dalapon, irrespective of the rate used, gave better control of Johnson grass than 2,3,6–TBA. There was no statistical difference among the dalapon treatments. However, as in 1955 (5), there was a tendency for two applications of 5 lb/A each to be as fully effective as 20 pounds in one application and somewhat more effective than single applications of 10 or 15 pounds. In contrast to the dry 1956 season, the spring and summer of 1957 was characterized by almost optimum moisture. Under these conditions, dalapon

Table 6. Johnson grass control with chemicals on noncropped areas near Experiment, Georgia, 1956 and 1957.

Chemical	Rate lb/A	1956 test		1957 test	
		J. grass plants per sq. yd.	Pct. control	J. grass plants per sq. yd.	Pct. control
Dalapon	2.5 + 2.5	6.0	87.7	—	—
Dalapon	5.0	16.0	67.1	—	—
Dalapon	5.0 + 2.5	4.0	91.8	—	—
Dalapon	2.5 + 5.0	2.3	95.3	—	—
Dalapon	5.0 + 5.0	0.3	99.4	2.0	98.9
Dalapon	10.0	2.6	94.7	10.6	94.2
Dalapon	15.0	—	—	5.6	97.0
Dalapon	20.0	0.6	98.8	14.3	92.9
Dalapon	30.0	—	—	13.0	92.9
2,3,6–TBA	30.0	41.6	14.5	—	—
Untreated check	—	48.6	0.0	181.0	0.0
LSD 5 pct level		14.7	—	11.1	—
LSD 1 pct level		20.0	—	15.5	—

in two 5 pound applications was significantly better than 20 pounds in a single treatment (Table 6). The increased effectiveness of the repeated 5 pound treatment over a single 30 pound application closely approached significance when the difference was tested with either conventional LSD's or Duncan's Multiple Range Test. There were no significant differences among single dalapon applications of 10, 15, 20, or 30 pounds. A consistent but non-significant decrease in percentage control occurred in 1955 (5), 1956, and 1957 when the rate applied was increased from 5 pounds repeated twice to 15, 20, or 30 pounds in one application.

In 1957, under adequate moisture conditions, observations made within a few days after herbicidal applications showed that the higher the rate of dalapon the more rapid and severe were the phytotoxic symptoms which developed. On the other hand, for the past 3 years, plants that received two repeated dosages of 5 pounds each did not show severe necrotic effects until approximately 1 week following the second application or 2 weeks after initial treatment. These observations indicate that the rapid necrosis induced by higher rates is undesirable and suggest that advanced necrosis interferes with further translocation. Consequently, final control of Johnson grass with higher rates of dalapon is reduced as compared to lower repeated applications. The greenhouse data showed that dalapon is absorbed very rapidly after application but that about 2 weeks are required for maximum apparent translocation to the rhizomes. The field observations presented above and the greenhouse data are in close agreement. Apparently, absorption of dalapon below a certain critical threshhold level contributes to final control but above this level further absorption promotes acute foliar necrosis which in turn reduces further translocation to the rhizomes and diminishes the final phytotoxic effect.

Field evaluation trials, pre-planting experiments.

The results of preliminary investigations for the control of Johnson grass with chemicals as preplanting treatments are shown in Table 7. No other material or combination of chemicals, with the exception of dalapon + amitrol was nearly as satisfactory as dalapon for the control of Johnson grass. There was no injury to corn or cotton planted 2 months and 1 month after herbicidal applications at Plains and Experiment, respectively.

At Experiment in 1956 (Table 8) all rates of dalapon gave good to excellent Johnson grass control. There were no statistical differences in control at the 5 percent level among overall rates of dalapon, levels of this herbicide within a given disking, or among disking means. There were significant differences between the averages for any treatment and the corresponding check plots. A high level of variation among the plots apparently prevented expression of valid statistical differences among rates of dalapon. Certain trends were evident, however, both from data and observations throughout the season. If the soil was disked 4 weeks after sprays were applied, decreased control resulted, especially following single dalapon appli-

Table 7. Control of Johnson grass in 1955 with foliar herbicidal applications as pre-planting treatments at Experiment and Plains, Georgia.

Treatment	Rate lb/A	Plains test		Experiment test	
		J. grass plants[a]	Pct. control	J. grass plants[a]	Pct. control
Dalapon	10	6.4	92.5	6.7	94.1
Dalapon	15	2.5	97.1	4.5	96.0
Dalapon	20	3.2	96.3	12.5	88.9[b]
Amitrol	4	76.2	10.2	32.3	71.2
Dalapon + amitrol	10+2	5.9	93.1	3.8	96.6
2,2,3–TPA	10	47.0	44.6	—	—
2,2,3–TPA	20	24.6	71.0	12.6	88.8
2,2,3–TPA + amitrol	10+2	44.6	47.5	21.0	81.3
4–CPA	20	—	—	32.3	71.2
Check	—	84.8	0.0	112.0	0.0
LSD 5 pct level		32.4	—	43.5	—
LSD 1 pct level		44.3	—	59.6	—

[a]Each figure is an average of three replicates. The shoots at ground level in four 8 x 1 foot quadrats at Plains and three 8 x 1 foot quadrats at Experiment in each plot were counted over the crop rows. Counts were made 18 weeks after chemicals were applied.

[b]Some of these plots were located in areas from which the soil eroded severely. Soil erosion and subsequent exposure of rhizomes to sunlight before herbicidal action was completed reduced the effectiveness of the treatments.

cations of 10, 15, and 20 pounds. More plants recovered after the delayed disking and the regrowth that occurred was more vigorous than following earlier diskings, especially on the 20 pound plots. If the time intervals between the repeated 5 pound applications are compared, the results generally favored 7 to 10 days between applications instead of 2 or 4 days. In contrast to experiments on non-cropped areas, split applications of 5 pounds each did not give consistently better results than single 10 pound treatments except where the plots were disked 4 weeks after treatment. In addition, the time intervals required for the utilization of split applications would delay planting unduly. Dalapon in a single application of 15 pounds or two 5 pound applications 10 days apart gave the most consistent results on the plots disked 2 or 3 weeks after treatment. Continual dry conditions and crusted soil surface during 1956 caused poor germination of the corn, cotton, sorghum, and soybeans planted 1 week after each disking; consequently, valid notes on herbicidal residues could not be obtained.

At Plains in 1956 (Table 9) dalapon at dosages of 10, 15, and 20 lb/A gave equally effective control of Johnson grass and did not injure corn, cotton, field peas, and peanuts planted 3 weeks after treatment or 2 weeks following disking. Residues of 2,3,6–TBA caused severe injury to all crops, especially with the 20 pound rate. In the 1957 Plains test, rates of dalapon varying from 5 to 20 lb/A gave good to excellent Johnson grass control. Dry weather conditions prevented adequate emergence of corn planted 4 weeks after spraying. In 1957 at Experiment all rates of dalapon gave fair to excellent control (Table 9). No apparent injury occurred to corn planted 0, 7, or 14 days after diskings made 7 or 14 days subsequent to spray applications of 5 or 10 lb/A. Following a 15 pound application of dalapon, height reduction of corn plants resulted when corn was planted on the day of disking 1 week after treatment. No apparent

Table 8. Control of Johnson grass with pre-planting herbicides applied to Johnson grass foliage and followed by disking at Experiment, Georgia, 1956.

Rate of dalapon lb/A	No. of applications	Days between applications	Total lb applied	Interval between initial treatment and disking[a b]						Average	
				2 weeks		3 weeks		4 weeks			
				No. of stems per sq. yd.	Pct. control	No. of stems per sq. yd.	Pct. control	No. of stems per sq. yd.	Pct. control	No. of stems per sq. yd.	Pct. control
5	2	10	10	3.0	95.4	2.0	94.4	10.0	86.5	5.0	91.4
5	2	7	10	2.7	95.8	5.3	85.0	9.0	87.8	5.7	90.2
5	2	4	10	12.7	80.2	3.6	89.9	14.3	80.6	10.2	81.4
5	2	2	10	12.3	80.8	3.6	89.9	14.0	81.0	10.0	82.7
10	1	–	10	8.0	87.5	4.0	88.7	22.0	70.2	11.3	80.5
15	1	–	15	4.3	93.3	1.6	97.0	13.3	82.0	6.4	89.0
20	1	–	20	4.0	93.8	5.3	85.0	20.6	72.1	10.0	82.7
Check	–	–	—	64.0	0.0	35.3	0.0	73.6	0.0	57.7	0.0
LSD 5 pct level for average treatment means										13.5	
LSD 1 pct level for average treatment means										18.1	

[a] LSD 5 pct level for treatments means within a disking 23.4.
LSD 1 pct level for treatments means within a disking 31.4.
[b] LSD 5 pct level for two disking means for a given treatment 21.0.
LSD 1 pct level for two disking means for a given treatment 32.1.

Table 9. Control of Johnson grass with foliar herbicides as pre-planting treatments at Plains, Georgia (1956 and 1957) and Experiment, Georgia (1957).

Chemical	Rate lb/A	Plains—1956		Plains—1957		Experiment—1957			
						Disked 1 week after treatment		Disked 2 weeks after treatment	
		Plants per sq. yd.[a]	Pct. control	Plants per sq. yd.[a]	Pct. control	Plants sq. yd[a]	Pct. control	Plants sq. yd[a]	Pct. control
Dalapon	5[b]	—	—	—	—	1.4	85.6	3.3	78.3
Dalapon	5	—	—	5.4	89.4	1.6	83.5	1.3	91.5
Dalapon	10	4.6	91.7	2.9	94.4	2.2	77.4	0.8	94.8
Dalapon	15	4.3	92.2	1.4	97.3	1.8	81.5	1.3	91.5
Dalapon	20	4.6	91.7	1.5	97.1	0.6	94.0	2.2	85.6
2,3,6–TBA	10	35.0	36.4	—	—	—	—	—	—
2,3,6–TBA	20	25.3	54.0	—	—	—	—	—	—
Check	—	55.0	0.0	50.0	0.0	9.7	0.0	15.2	0.0
LSD 5 pct level		15.5	—	8.0	—	4.0	—	4.0	—
LSD 1 pct level		21.7	—	11.2	—	5.4	—	5.4	—

[a]Each figure is an average of three or four replicates and from 1 to 8 square yard quadrats depending on the test involved and density of the Johnson grass stand.
[b]No additional surfactant was added to the spray solution.

residual toxicity resulted from the other plantings following 15 pound treatments. Increased toxicity to corn plants resulted from the use of 20 lb/A, especially if the soil was disked 1 week after herbicidal applications and the corn planted immediately after disking.

It was noted that good agreement between the results of the greenhouse translocation studies and the pre-planting field experiments was obtained, that is, if disking after treatment in the field was done at approximately 2 or 3 weeks instead of 1 or 4 weeks, generally better control of Johnson grass resulted. The greenhouse tests indicated that apparent toxicity of dalapon in Johnson grass rhizomes was greater 2 weeks after spraying than at 1 or 4 weeks. Consequently, field diskings predicated on the greenhouse data would be expected to give the best results. This does not imply that the action of dalapon is completed within 2 weeks after spraying. Observations and other data suggest that the herbicidal action of this material in Johnson grass rhizomes, especially on undisturbed stands, extends over a considerable number of weeks. If soil erosion occurred during this extended period of activity and the rhizomes were exposed to sunlight, increased sprouting and decreased control resulted.

Difficulty with Johnson grass seedlings emerging during the season of treatment or the year after treatment has been encountered in only one field test during the past 4 years. This is in contrast to certain other areas in the Johnson grass belt where seedlings present an extremely serious problem after the established stand is controlled. Occasionally, Johnson grass seedlings are a problem in the Georgia Piedmont Plateau, but the situation apparently is not general or serious. Observations and limited data during the past 4 years indicate that seed set in Johnson grass under Georgia conditions is erratic, variable, and generally low. Percent germination of normal embryos, however, is high.

SUMMARY

Data on the penetration, absorption and translocation of several herbicides in Johnson grass under greenhouse conditions and their effectiveness for the control of this weed under field conditions are presented; the principal results may be summarized as follows:

1. Of several herbicides studied, dalapon was the one most effectively and consistently translocated from Johnson grass foliage to the rhizomes. Translocation of dalapon was not critically affected by low soil moisture, reduced sunlight, or use of additional wetting agent in the spray solution.
2. Growth responses indicated that dalapon penetrated Johnson grass foliage rapidly during the first hour after treatment.
3. An increase in pH from 4.5 to 6.5 or 9.0 decreased absorption of dalapon, but exposure to a 48-hour dark period before treatment or an 18° F reduction of the average air temperature (from 78 to 60° F) after treatment did not greatly affect absorption.
4. The most effective herbicide for the control of established Johnson grass on noncropped areas was dalapon applied in the spring when the foliage was 12 to 24 inches tall at a rate of 5 lb/A repeated in 7 to 10 days or a single application of 15 to 20 lb/A.
5. As a pre-planting foliage treatment for Johnson grass control on two Georgia soil types, a single application of dalapon at a rate of 15 lb/A gave the most consistently satisfactory results.
6. A probable basis is discussed for the partial inverse relationship observed between the rate of dalapon applied and the control of Johnson grass under field conditions.

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A Method for Inducing Dormancy in Wild Oats (*Avena fatua* L.)[1]

J. R. Hay and B. G. Cumming[2]

The wild oat (*Avena fatua* L.) is considered to have spread originally from Asia; it is widely distributed throughout Europe and its advent in North America is attributed to introduction by immigrants from there (8, 13). The species presents a very serious weed problem in the prairie regions of Canada and northwestern United States (18). In Britain it has become prevalent in some regions as a result of intensive cropping to cereals (17). Up to 70 bushels of wild oat seeds per acre have been estimated to occur in the soil in badly infested fields in western Canada (12). This seed cannot all be stimulated to germinate by cultural practices and may remain viable in the soil for at least 3 years (4). The wild oat problem would be solved if the seed in the soil could be destroyed. There are two ways to achieve this: firstly, by stimulating the dormant seed to germinate so that the plants can be killed by cultivation or, secondly, by killing the dormant seed through the addition of toxic materials. Up to the present, attempts to do either of these have been unsuccessful; thus, investigations to determine the factors involved in dormancy are of primary importance.

Basic studies on wild oats have been complicated because samples of seed collected from the field vary considerably in their degree of dormancy and also because dormancy is lost upon storage under ordinary laboratory conditions. This paper describes a method of inducing dormancy in wild oats and compares this dormancy with that occurring under natural conditions.

Review of Literature

Atwood (1) showed that germination of dormant wild oats could be increased slightly by removing the hulls and increased still further by puncturing the testa. Johnson (9) reported that the germination of dormant wild oats was increased if the seeds were treated with potassium nitrate. The above treatments have been reported to increase germination in a number of other species. Johnson also reported that wild oats could develop "an induced secondary dormancy". A sample of seed failed to germinate when fully imbibed at temperatures favorable for germination. In a test 3 months later, this seed was more dormant than other seed from the same original lot which had been in continuous storage and was gradually losing its dormancy.

Induced secondary dormancy has been reported in seed of *Brassica alba* (10), *Ambrosia trifida* (6), and a species of *Xanthium* (16). In

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the latter two species it was shown that embryos became dormant when the seeds were kept imbibed at high temperatures with oxygen pressures subminimal for germination. Naylor and Christie (14) have reported wide variation in dormancy of freshly collected wild oat seed. They also reported that nondormant wild oats became dormant when the imbibed seeds were placed in an atmosphere of nitrogen for 6 days; the level of dormancy increased with the length of time under nitrogen. Kommedahl et al. (11) have recently demonstrated that soaking wild oats seeds in water under a partial vacuum substantially lowers germination percentages.

The results of Johnson (9) on the influence of light on the germination of wild oats were inconclusive. Recently Black and Naylor (3) and Cumming (5) have reported an inhibitory effect of light on the germination of wild oats. An interaction between light and dormancy was also shown since total germination of nondormant wild oats was obtained under conditions where light was inhibitory to partially dormant seed (5).

MATERIALS AND METHODS

In a number of the tests referred to below, wild oats were immersed in water; i.e. they were placed in 125 ml Erlenmeyer flasks which were then completely filled with water. By alternately depressing and releasing the rubber stoppers in the flasks much of the air could be forced out of the hulls. All treatments were replicated at least twice with 50 or 100 seeds per replication.

For the germination tests after the immersion periods, seeds were placed in 9 cm petri dishes on two sheets of filter paper moistened with 5 cc of distilled water. The dishes were then placed in a dark room maintained at 25 ± 1° C and unless otherwise stated received occasional red or green light. Seed was brought out to the laboratory for such treatments as removal of the hulls and puncturing the seed coats. Seed was classified as nondormant if close to 100 percent germination was obtained at 20 to 25° C, in darkness or in light. The term "hulls" refers to the lemma and palea; the term "seed coat" refers to the testa.

The majority of the wild oats used for these tests were collected from a plot-field in Ottawa in 1955. This seed was fully dormant on August 16, 1955, even with hulls removed; by September 26, 1955, samples of this seed germinated completely (i.e. the seed was nondormant). Seed collected from the same field in 1957 was also used, as well as seed from western Canada, to duplicate certain critical tests.

Oxygen uptake measurements were made using simple volumetric respirometers made from 5-ml vaccine bottles each with the bases removed and fitted with a 0.2 ml pipette. Their construction and use have been described previously (15).

RESULTS AND DISCUSSION

Wild oats were immersed in water for varying periods of time and subsequently treated in various ways as indicated in Table 1. When

the seeds had been immersed for 64 hours or more and were then transferred to moistened filter paper they did not germinate if their hulls were left on. Dehulling increased the germination but after 96 hours immersion the seed failed to germinate even when dehulled. The ungerminated seeds were still viable at the end of the experiment since removal of the hulls and puncturing the seed coats resulted in almost complete germination.

Table 1. Percent germination of wild oat seeds receiving different treatments after being immersed in water for varied lengths of time at 25° C.

Hours immersion	Percent germination with		
	Hulls on	Hulls removed after immersion	Hulls removed and seed coat punctured, after immersion
0	95	100	100
16	40	90	95
32	20	75	75
48	20	65	85
64	0	30	100
80	0	45	90
96	0	10	95
112	0	10	90

In further tests, seeds were immersed for 48 hours and then transferred to moist filter paper for 96 hours. When these seeds were dehulled at the end of this time less than 10 percent germinated, whereas seeds dehulled immediately after the 48 hour immersion period gave approximately 65 percent germination. Thus, a 2 day immersion plus 4 days on filter paper was a convenient method of obtaining fully viable seeds less than 10 per cent of which germinated even if the hulls were removed.

It was also found that a lower percent germination was obtained if the water for soaking was boiled for 10 minutes and cooled to room temperature just prior to use.

The response of wild oats under these immersion conditions was compared with that of *A. sativa* L. var. Rodney. It was found that the seeds of *A. sativa* were killed if soaked in water for more than 24 hours, a period which was not lethal to *A. fatua*. However, when transferred to filter paper after 12 hours immersion, the cultivated oats were still viable. Table 2 shows percent germination at the end of 8 days on filter paper. Hulls of half the number of seeds were

Table 2. Percent germination of seed of *A. fatua* and *A. sativa* 8 days after immersion in water for 12 hours at 25° C. Hulls were removed from half the number of seeds 4 days after transferring to moist filter paper.

Species	Percent germination after 8 days	
	Hulls on throughout	Hulls removed at 4 days
A. fatua	15	25[a]
A. sativa	37	94

[a]The ungerminated seed was still viable.

removed after 4 days on filter paper. Although there was a reduction in germination when hulls were left on, 94 percent of the cultivated oats germinated if the hulls were removed. On the other hand only 25 percent of the wild oat seeds germinated even with hulls removed. All seeds were still viable and would germinate if the seed coats were punctured. Thus, *A. sativa* did not survive prolonged immersion, and there were no signs of dormancy such as was shown by wild oats whereby the seed, although viable, failed to germinate after dehulling.

Table 3 shows the uptake of oxygen by wild oats after being immersed in water. Readings were taken 24 hours after the removal of hulls or puncturing of seed coats. The data show that removal of hulls immediately after the immersion period, or puncturing the seed coats (previously shown to bring about germination) resulted in high rates of oxygen uptake. Considerably lower values were obtained if the hulls were left on throughout or if the hulls were not removed until after 4 days on filter paper; that is, under conditions which led to low germination. These seeds were capable of 100 percent germination if dehulled and pricked, but since they were in a state of low metabolic activity (as indicated by O_2 uptake) it was concluded that a type of dormancy had been induced. Tests were then conducted to compare this artificially induced dormancy with that of natural field dormancy.

Table 3. Oxygen uptake by wild oat seeds and percent germination after immersion in water for 48 hours at 25° C.

Treatments[a]	O_2 uptake cc/hr/20 seeds	Percent germination[b]
48 hr immersion in water, then,		
Hulls left on	0.18	0
Hulls removed	0.81	75
Hulls removed and punctured	1.07	100
48 hr immersion plus 4 days on filter paper, then,		
Hulls left on	0.17	0
Hulls removed	0.23	10
Hulls removed and punctured	0.97	100

[a]Readings taken 24 hours after these treatments.
[b]From Table 1 and text.

Two lots of wild oat seed were planted at 1-inch depth in soil in the greenhouse. One lot consisted of seeds which had not germinated on filter paper 4 days after being immersed in water for 48 hours; the other lot (controls) received no prior treatment. In four separate tests an average of only 17 percent of the pre-immersed seeds germinated within 8 weeks after planting, as compared to 92 percent germination for the controls. Ungerminated pre-immersed seeds were recovered from the soil at the end of the last test. After dehulling and puncturing the seed coats, 90 percent of the seeds recovered were still viable. Other lots of seed with induced dormancy were allowed to dry out, and when tested 3 and 4 weeks later they still possessed a high level of dormancy. Bibbey (2) has pointed out that many seeds in the soil (including wild oats) are nondormant by the

end of the winter; some do not germinate during the following summer. Therefore, much of the seed in the soil may actually be in a state of secondary dormancy.

Table 4 shows the influence of different chemicals on the wild oats possessing artificially induced dormancy. KNO_3, $NaNO_3$, H_2O_2 and gibberellic acid (GA) all increased percent germination. Previous tests by ourselves and others (7, 9) had shown that these materials increased germination of naturally dormant wild oats.

Seeds were placed on moist filter paper in darkness (dishes wrapped in aluminum foil) and in light (500 f.c. from incandescent

Table 4. Percent germination of wild oat caryopses with induced dormancy in presence of different chemicals at 25° C.

Chemical	Percent germination at 4 days
KNO_3 0.2%	70
$NaNO_3$ 0.2%	70
H_2O_2 0.034%	74
Gibberellic acid 0.01% (100 ppm)	94
Control	20

plus fluorescent light source, 8-hour daylength) at 25° C. The results in Table 5 are typical of those of a number of tests on the effect of light on germination of nondormant wild oats (1955 seed), wild oats with induced dormancy (72 hour pre-immersion in water of 1955 seed) and with natural dormancy (1957 seed). Intact and dehulled seed was utilized. The nondormant seed germinated equally well regardless of the light treatment. On the other hand, germination of grains with either induced dormancy or natural dormancy was lower in light than in darkness.

Table 5. Percent germination of different samples of wild oat seeds in light (8 hour daylength) and in darkness at 25° C.

Seed sample	Seed condition	Percent germination at 4 days			
		Hulls on		Hulls removed	
		Light	Dark	Light	Dark
1955 Seed	Nondormant	100	100	100	100
1955 Seed	Induced dormancy	0	20	30	70
1957 Seed	Natural dormancy	0	30	30	70

Thus, seeds with either natural dormancy or induced dormancy responded in a similar way to treatment with KNO_3, H_2O_2, GA, to light and to removal of hulls and puncturing the seed coats. The method of artificially inducing dormancy by water immersion warrants future use and further investigation.

A suggested procedure for inducing dormancy is to soak the seed for 48 hours in boiled water after which the seeds should be transferred to moist filter paper. A constant temperature of 25° C for these operations has proven satisfactory. If the few seeds that germinate under these conditions are removed after 4 days, the remain-

der of the seeds will be almost completely dormant. This procedure has given satisfactory results with seed collected in different years and from various locations. The method provides a simple means of obtaining a constant supply of seed with a high degree of dormancy. This eliminates a dependence on a supply of freshly harvested seed that may be rapidly losing its dormancy or which may have only a low degree of dormancy at harvest time.

Results of investigations of the mechanism responsible for the induction of secondary dormancy will be presented in a subsequent paper.

SUMMARY AND CONCLUSIONS

1. A secondary dormancy was induced in nondormant wild oats when immersed in water. Seed failed to germinate when dehulled after immersion in water for 96 hours, or when dehulled 4 days after being transferred to moist filter paper following 48 hours soaking. The seeds were still viable since they germinated if the seed coats were punctured.

2. This dormant seed had a low oxygen uptake, as compared to nondormant seed, when fully imbibed at 25° C. Puncturing the seed coats and treating the seed with KNO_3, $NaNO_3$, H_2O_2 or gibberellic acid increased the germination of seed with artificially induced dormancy just as with natural dormancy. White light, as compared to darkness, decreased the germination of seed with induced and natural dormancy. The pre-immersed seed also remained dormant when transferred to soil. In all respects tested, the induced dormancy was similar to natural dormancy.

3. A simple procedure for obtaining a constant supply of seed with a high degree of dormancy is presented. It is suggested that this could eliminate the necessity of working with freshly harvested seed which may be rapidly losing its dormancy or which may have a low degree of dormancy at harvest time.

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Methods of Obtaining Field and Laboratory Germination of Seeds of Bindweeds, Lady's Thumb and Velvet Leaf[1]

G. P. Steinbauer and Buford Grigsby[2]

Studies of effects of weed competition on crop yields, and of procedures used in screening herbicides as to effectiveness for weed eradication, often require the planting of weed seeds under field or greenhouse conditions. Because of the many factors that contribute to delayed germination, field and greenhouse stands of weeds obtained in this way are often irregular and slow in developing. Although methods for obtaining laboratory germination of weed seeds have been worked out for many species the methods are not always applicable for field planting, particularly where removal of seed coats or use of alternations of widely different temperatures are advocated.

The following report describes methods which the authors have found successful not only for laboratory germination but also for obtaining germination of certain weed seeds in the greenhouse and field. The four species under consideration are persistent and troublesome weeds in Michigan and adjacent states. The causes of delayed germination have been studied and methods for obtaining laboratory germination of the seeds have been proposed (1, 2, 3, 4, 5).

Germination of Seeds of Field and Hedge Bindweeds

Field bindweed (*Convolvulus arvensis* L.) and hedge bindweed (*Convolvulus sepium* L.) tend to produce seeds with coats that are impermeable to water and therefore remain as "hard seeds" at the end of a germination test. The dormancy and germination characteristics of one of these, field bindweed, have been extensively studied by Brown and Porter (1). They emphasize that while the proportion of the seeds that are impermeable varies, it may frequently include most of the seeds of a sample. Impermeability of the seed coat was found to persist for as long as 50 years when the seeds were in dry storage. Seeds of bindweed harvested at Michigan State University in 1954 still showed over 96 percent of hard seeds in 1957.[3] This impermeability can be effectively broken by immersion of the hard seeds in concentrated sulfuric acid for 1 hour, followed by thorough rinsing in water (1).

Laboratory germination of field bindweed seeds is readily obtained by placing the seeds on blotters in petri dishes, using water as the moistening agent, and subjecting the seeds to either constant 20° C, constant 30° C or a daily alternation of 20° C for about 16 hours and 30° C for 8 hours. Germination of the permeable seeds should

[1]Published with approval of the Director as Paper No. 2223 Journal Series, Mich. Agri. Exp. Sta., supported in part by funds allocated by the NC–10 Regional Technical Committee.

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[3]Steinbauer, G. P., and Grigsby, B. Unpublished data 1957.

be complete in 5 days. The viability of the "hard seeds" can be determined by immersion of the seeds in conc. sulfuric acid for 1 hour, followed by a half hour rinse in running water, after which the seeds should be returned to the germinator. Final readings are made at 7 days. Seeds are considered as germinated when combined hypocotyl and primary root have attained a length of about 1 centimeter and do not exhibit morphological defects (see Figure 1).

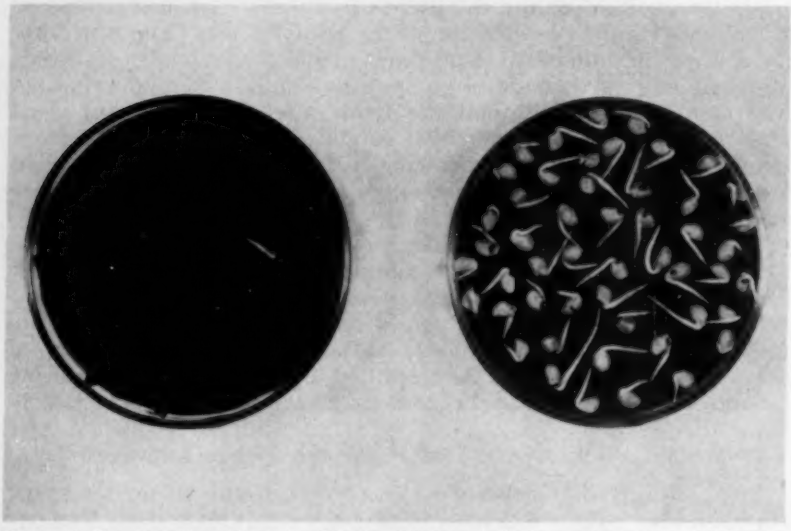

Figure 1. Germination of seeds of hedge bindweed. Left, seeds on top of blotters in petri dish, moistened with water, 20° C 16 hrs., 30° C 8 hrs. daily. Right, seeds in conc. sulfuric acid 1 hr., rinsed in running water one half hr., then as above. Germination counts at 7 days.

In preparing the seeds for field or greenhouse planting the seeds should be treated with acid, rinsed, and surface dried to facilitate handling during planting. The effectiveness of the acid treatment in securing germination of bindweed seeds in the laboratory and in the field is illustrated in Table 1.

Table 1. Laboratory germination and field emergence of bindweed seeds.[a]

Treatment	Percentage germination	
	Laboratory[b]	Field[c]
Hedge bindweed		
Control	2	2
Conc. H_2SO_4 1 hr., one half hour rinse in water	96	92
Field bindweed		
Control	3	0
Conc. H_2SO_4 1 hr., one half hour rinse in water	98	60

[a]Seeds harvested September 1955, tested June 1956.
[b]Seeds placed on top of 2 thicknesses of blotters in petri dishes, moistened with water, at 20° C, 16 hrs., and 30° C 8 hours daily. Results based on duplicate 100 seed samples per treatment with germination counts at 7 days.
[c]Results based on duplicate 100 seed samples.

GERMINATION OF SEEDS OF VELVET LEAF

Seeds of velvet leaf *(Abutilon theophrasti Medic.)* often possess seed coats impermeable to water. However, the proportion of seeds that are impermeable is more variable than in the bindweeds, and impermeability tends to disappear in a shorter time. Thus one lot of velvet leaf seeds harvested at Michigan State University in 1955 had 100 percent impermeable seeds at the first test period and yet nearly all had become permeable after 1 year of storage in the laboratory. Another lot harvested in 1956 showed only 7 percent hard seeds. Seeds stored at high relative humidities tend to become permeable more rapidly than those stored at low relative humidities.[4]

Laboratory germination of seeds of velvet leaf can be secured by the method of Everson (2). In this method the seeds are placed on blotters in petri dishes, using water as the moistening agent and maintaining the temperature at 2° C to 5° C for 2 days, then 35° C. Permeable seeds should germinate within 5 days. The viability of the hard seeds can be determined by mechanical scarification, or by immersion of the seeds in boiling water for 1 minute, then returning them to the germinator.

If a prior germination test indicates a low content of "hard" seeds no pretreatment may be required before greenhouse or field planting. When there is a high percentage of hard seeds or when maximum germination is desired, special treatment of the seeds must be given to render the hard seeds permeable. Although immersion of the hard seeds in boiling water for 1 minute, as suggested under laboratory procedure, will render them permeable, it is often injurious to permeable seeds as shown in Table 2. Immersion of the seeds in concentrated sulfuric acid for 15 minutes, followed by a half hour rinse in running water, makes the hard seeds germinable without injury to the non-hard seeds. Surface drying of the seeds following acid treatment may be desirable to facilitate handling.

Table 2. Effect of treatment on emergence of velvet leaf seedlings in field plantings.[a]

Treatment	Percentage emergence[b]
Control	55
Seeds boiled 1 min. and cooled prior to planting	40
Seeds in conc. H_2SO_4 15 min. and one half hour rinse in water prior to planting	86

[a]Data based on 1955 seed, tested 8 months after harvest.
[b]Data based on duplicate lots of 100 seeds each.

GERMINATION OF THE SEEDS OF LADY'S THUMB

The dormancy and germination characteristics of the smartweeds *(Polygonum spp.)* have been studied extensively by Justice (3, 4). Primary dormancy is common in the group and sometimes it may persist for long periods of time. In some species it may gradually

[4]Steinbauer, G. P., and Grigsby, B. Unpublished data 1958.

disappear during dry storage. Most of them require moist stratification of the seeds at low temperatures to complete the after-ripening process. However, the time required for such after-ripening changes may be materially shortened by corrosion of the seed coats with sulfuric acid (4) or by complete removal of the coats (5). Although the latter method is highly effective when small numbers of seedlings are required it is hardly practical for field plantings because of the labor involved.

For laboratory germination of the seeds of lady's thumb, Everson (2) recommends a daily alternation of temperatures between 2 to 10° C and 35° C for 14 days, after which the seeds are kept at a daily alternation of 20° C for 16 hours, and 30° C for 8 hours. The seeds are kept on the top of thoroughly moistened silica sand in petri dishes. Final counts are made in 21 days. We have obtained equally good and usually more uniform results by immersing the seeds in concentrated sulfuric acid for 15 minutes, rinsing the seeds one half hour in running water, placing them on blotters in petri dishes at 5° C for 1 week, after which germination can be completed at the 20 to 30° C temperature alternation schedule.

Seeds intended for field or greenhouse germination may be treated with acid, followed by the water rinse, stratified at 5° C for 1 week and surface dried to facilitate handling. Although seeds often germinated better in the laboratory when 0.2% KNO_3 solution was used as moistening agent this was not true for seeds planted in soil.

The response of a 1955 sample of lady's thumb seeds to various treatments in the laboratory and in the field 8 months after harvest of the seeds is shown in Table 3.

Table 3. Field and laboratory germination of seeds of lady's thumb.[a]

Treatment prior to field or laboratory planting	Percentage germination	
	Laboratory[b]	Field
Control	1	2
Prechill (5° C) 1 wk.	37	30
Conc. H_2SO_4 15 min., one half hour rinse in water	8	12
Conc. H_2SO_4 15 min., one half hour rinse in water, prechill (5° C) 1 wk.	80	75

[a]Seeds harvested in September 1955 and tested in June 1956.
[b]Seeds placed on top of 2 thicknesses of blotters in petri dishes, moistened with 0.2% KNO_3 solution, at 20° C, 16 hrs., and 30° C 8 hrs. daily. Germination counts made at 21 days. Duplicate 100 seed samples per treatment.

CONDENSED SCHEDULE OF GERMINATION METHODS

Velvet leaf.

Laboratory germination:

Seeds should be placed in petri dishes, on 2 blotters moistened with water, and kept at 2 to 5° C 2 days then 35° C. Count at 5 days. Seeds "hard" at the end of test should be placed in boiling water for 1 minute or in conc. sulfuric acid 15 min., rinsed in running water one half hour, and returned to blotters at 35° C. Conclude the test at 7 days.

Field germination:

Seeds should be placed in conc. sulfuric acid for 15 min., rinsed in running water for one half hour, and surface dried to facilitate handling. If a prior laboratory test has indicated only a small percent of hard seeds the above acid treatment may be omitted. However the acid and rinse treatment may be used safely even if permeable seeds are present.

Field and hedge bindweeds.

Laboratory germination:

Seeds should be placed in petri dishes, on top of 2 blotters moistened with water, and kept at 20 to 30° C.[5] Count at 5 days. Seeds "hard" at end of the test should be placed in conc. sulfuric acid 1 hour, rinsed one half hour in running water, then returned to blotters at 20 to 30° C.[5] Final count should be made at 7 days.

Field germination:

Treat seeds with acid and rinse as indicated above. Dry the seeds and plant.

Lady's thumb.

Laboratory germination:

Place seeds in conc. sulfuric acid 15 min., rinse one half hour in running water, prechill between blotters in petri dishes, using 0.2% KNO_3 as moistening agent, at 5° C for 1 week, then keep at 20 to 30° C.[5] Count at 21 days.

Field germination:

Place seeds in conc. sulfuric acid for 15 min., rinse one half hour in running water, prechill between blotters, or similar substrates at 5° C for 1 week, surface dry and plant.

SUMMARY

Directions are given for securing germination of seeds of field and hedge bindweeds, velvet leaf, and lady's thumb, in the laboratory and in the field or greenhouse.

Because of the frequent occurrence of impermeable seeds in the first three, corrosion of the seed coats with concentrated sulfuric acid may be needed to induce germination.

Although dormancy of the seeds of lady's thumb can be overcome by stratification alone, the time required to do this can be materially shortened by a treatment combining the use of concentrated sulfuric acid, and a low temperature stratification.

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Neburon as a Selective Herbicide for Tartary Buckwheat and Wild Buckwheat[1]

H. A. Friesen and D. E. Forsberg[2]

Tartary buckwheat (*Fagopyrum tataricum* (L.) Gaertn) and wild buckwheat (*Polygonum convolvulus* L.) are annual weeds which are becoming increasingly prevalent on the Canadian prairie. Tartary buckwheat has become widespread in north central Alberta where over 2,500,000 acres are estimated to be infested, with over 500,000 acres heavily infested. The infested area is growing larger and in recent years has begun spreading into the neighboring province of Saskatchewan. Only one infestation, some 300 acres in size, has been reported in Manitoba. Because it is similar in size, the seed of tartary buckwheat is extremely difficult to remove from wheat, oats and barley and under the Canada Seeds Act, grains containing it may not be sold for seed. Commercial grain containing these seeds is severely degraded. As an impurity in wheat, the seed causes discolored flour. Consequently, the spread of this weed is being viewed with considerable alarm in western Canada.

Wild buckwheat is far more widespread than tartary buckwheat. In Manitoba and Saskatchewan it ranks second only to wild oats as the worst annual weed menace. Manitoba has an estimated 4,000,000 acres infested, one-half of which is heavily infested, while Saskatchewan has some 7,000,000 acres or 20 percent of its cultivated acreage heavily infested. In Alberta it is found on over 3,000,000 acres with about 500,000 acres heavily infested. Wild buckwheat is a strong competitor for nutrients and light. Furthermore, its twining habit of growth tends to cause the grain to lodge which makes harvesting difficult and losses are often high.

The relative ineffectiveness of cultural methods for the control of both of these weeds (4, 7) stimulated interest in the use of herbicides for this purpose. Field observations have shown that the phenoxy-type herbicides such as 2,4–D, (2,4–dichlorophenoxyacetic acid) give a measure of suppression but the results have generally been inconsistent and often unsatisfactory (1, 2, 3, 5, 6, 8, 9). It is the purpose of this paper to present the results of field trials with neburon, 1–*n*–butyl–3–(3,4–dichlorophenyl)–1–methylurea, an herbicide which has appeared very promising for the selective control of both buckwheats growing in competition with cereal grains.

Materials and Methods

Tartary buckwheat trials. In 1956 a preliminary non-replicated trial of neburon,[3] a wettable powder, 18.5 percent active ingredient,

[1]Contribution from the Division of Field Husbandry, Soils and Agricultural Engineering, Experimental Farms Service, Canada Dept. of Agriculture.

[2]Sr. Agronomist, Experimental Farm, Lacombe, Alberta and Sr. Agronomist, Experimental Farm, Scott, Saskatchewan, respectively.

[3]Experimental sample supplied by E. I. Du Pont de Nemours & Co., Wilmington, Delaware.

was laid down on tartary buckwheat in barley at the Experimental Farm, Lacombe. The chemical was applied at five rates and two stages of weed and crop growth. The results were assessed by weed counts only and no attempt was made to sample the barley for yield because of the lack of replication. In another preliminary trial, however, the effect of neburon on the yield of weed-free barley was tested at three rates with a control in a Latin square design.

The excellent kills of tartary buckwheat in 1956 suggested expansion of the trials in 1957. Failure of additional neburon supplies to arrive at Lacombe until mid-July permitted only single square rod plot trials at the rates of 2 and 4 pounds per acre to be set out at the normal time of weed and crop growth in the spring. On July 20, 1957, a field plot trial with neburon at seven different rates of application was laid down in a randomized block design on buckwheat in very late seeded oats. The oats were in the early shot blade stage and some of the tartary buckwheat had begun to bud at the time of treatment. Also included in this trial were mixtures of neburon with the butyl ester of 2,4–D and of MCPA (2–methyl–4–chlorophenoxyacetic acid), the latter compounds being used at the rate of 5 and 6 ounces per acre, respectively, in the mixtures.

In all of the above trials neburon was applied in water with a knapsack sprayer at the rate of 100 gallons per acre. To assess the effect of volume of water used, a test of neburon at three rates viz.; 2, 3 and 4 pounds per acre in four volumes of water, viz.; 110, 165, 220 and 275 gallons per acre was conducted on a pure stand of tartary buckwheat. Additional treatments were applied in which neburon was mixed with the butyl ester of 2,4–D and the butoxy ethanol ester of 2,4–D. The buckwheat plants were in the 2- to 4-leaf stages of growth at time of treatment.

Wild buckwheat trials. At the Experimental Farm, Scott, in 1957, neburon was included in five tests dealing with the control of wild buckwheat. In a rectangular lattice design, neburon was applied at 4 and 6 pounds per acre, each in 80 gallons of water per acre with a knapsack sprayer, to a crop of Chinook wheat. These rates were applied when the wild buckwheat and grain were in the 2- to 4-leaf stage and again when in the 3- to 5-leaf stage. In another test with Fortune oats the same rates and volumes of water were applied on wild buckwheat, which varied in development from the 2-leaf to the 10-leaf stages. The oats were in the heading stage.

In July of 1957 three tests were laid down on a dense stand of wild buckwheat in the 2- to 6-leaf stage. In two of these tests, the rates ranged from ½ to 8 pounds per acre, each in 100 gallons of water per acre. In the third test neburon was applied at two rates viz.; 3 and 4 pounds per acre with four volumes of water, viz.; 100, 170, 230 and 285 gallons per acre being used as the diluent. Additional treatments were applied in which neburon was mixed with the butyl ester of 2,4–D and the butoxy ethanol ester of 2,4–D.

EXPERIMENTAL RESULTS

Tartary buckwheat 1956 trials. The results of the preliminary trial in 1956 showed that tartary buckwheat was completely eliminated by neburon sprayed at dosages of 3.2 pounds per acre or higher. At the 1.6 pound per acre dosage, applied during the 5-leaf stage, only 75 percent of the plants were killed, while this dosage applied during the bud stage resulted in less than 50 percent kill of plants. There was visible injury to the crop only when neburon was applied at 12.8 pounds per acre. At this rate the barley plants had fewer tillers than the plants in the untreated plots.

Neburon sprayed on barley plots, kept in a weed free condition, at 3.6 and 7.2 pounds per acre did not significantly increase or decrease the yield of grain. Furthermore, there was no evidence of effects on any morphological characteristics. The barley treated with neburon at 14.4 pounds per acre was stunted, tillering was greatly reduced and the yield was significantly lower than the untreated crop.

Tartary buckwheat 1957 trials. Post-emergence spraying on tartary buckwheat in the 2- to 4-leaf stage resulted in excellent kills. The untreated plots had 85 buckwheat plants per square yard while the plots treated with 2 and 4 pounds of neburon per acre had only 5 and 3 plants per square yard respectively. The treatments had no observable effect on the barley.

The results of neburon applications on tartary buckwheat at the first bud stage in oats are given in Table 1. It will be noted that dosages of neburon of 0.5 and 1 pound per acre did not materially

Table 1. Number and weight of tartary buckwheat and other weeds following various treatments with neburon alone or mixed with 2,4–D or MCPA, Lacombe, 1957.

Herbicide*	Rate lb/A	Dry weight—lb/A		Plants per square yard		
				Buckwheat		Others after spray
		Buck-wheat	Others	Before spray	After spray	
Neburon	0.5	139	300	36	47	244
Neburon + 2,4–D	0.5	186	150	44	42	171
Neburon + MCPA	0.5	193	54	54	67	142
Neburon	1.0	160	321	38	53	234
Neburon + 2,4–D	1.0	118	150	37	43	197
Neburon	1.5	86	300	38	43	305
Neburon + 2,4–D	1.5	64	128	42	35	154
Neburon	2.0	54	278	25	37	244
Neburon + 2,4–D	2.0	86	107	40	40	120
Neburon	3.0	21	171	24	16	184
Neburon	4.0	21	107	62	20	124
Neburon	6.0	10	128	42	13	150
Check		171	264	49	51	196

*The butyl ester of 2,4–D was used at 5 oz/acre in each mixture and the butyl ester of MCPA at 6 oz/acre.

reduce the number or dry weight of the tartary buckwheat plants. At dosages of 1.5 and 2 pounds per acre the number of plants was little affected but their dry weight was reduced by some 50 percent. The treated plants were stunted and the upper leaves were necrotic.

The mixing of the butyl ester of 2,4–D at 5 ounces per acre with each of the above dosages of neburon appeared to result in no better control of tartary buckwheat than neburon alone. Similarly mixing the butyl ester of MCPA at 6 ounces per acre with neburon at 0.5 pounds per acre did not enhance the control. Neburon at 3, 4 and 6 pounds per acre resulted in a decided reduction in the number of plants and a very great reduction in the dry weight of buckwheat, especially at the heaviest rate of application.

"Other" weeds were little affected by neburon except at the 4 and 6 pounds per acre rates. Lady's thumb (*Polygonum persicaria* L.) which made up the bulk of the "Other" weeds was reduced in number and weight by each of the heavy rates of neburon and the combination treatments. The butyl esters of 2,4–D and MCPA were compatible in mixtures with neburon and their effect on the "Other" weeds such as lady's thumb, stinkweed (*Thlaspi arvense* L.), lamb's quarters (*Chenopodium album* L.), wormseed mustard (*Erysimum*

Table 2. Number and weight of tartary buckwheat plants following treatment with neburon applied in various volumes of water, Lacombe, 1957.

Treatment		Rate of water gal/A	Plants/sq. yd.		Dry matter lb/A
Neburon—lb/A	Additive oz/A		Time of spray	16 days after spray	
1.....	None	165	416	420	354
2.....	None	165	375	0	0
2.....	2,4–D ester 5	110	455	0	0
3.....	None	110	246	0	0
3.....	None	165	240	0	0
3.....	None	220	333	0	0
3.....	None	275	365	0	0
3.....	2,4–D ester 5	110	327	0	0
3.....	2,4–DLV ester[a] 5	110	355	0	0
4.....	None	110	290	0	0
4.....	None	165	320	0	0
4.....	None	220	295	0	0
4.....	None	275	324	0	0
4.....	2,4–D ester 5	110	314	0	0
4.....	2,4–DLV ester 5	110	352	0	0
Check –.....	—— –	——	369	368	439

[a]Refers to butoxy ethanol ester of 2,4–D.

chieranthoides L.), and Russian pigweed (*Axyris amaranthoides* L.) appeared not unlike that expected of them when used alone. Moisture was in short supply for an 18-day period following treatment. This coupled with the advanced stage of growth of the tartary buckwheat may in part account for the very slow action of the neburon. The oats showed no signs of injury but yields were rendered meaningless by a severe early frost.

In Table 2 it will be noted that the volumes of water used as a diluent had no measurable effect under the conditions of this trial. Each dosage of neburon at 2 pounds per acre and higher gave complete kills, as is shown in Figure 1. The mixing of the butyl ester of 2,4–D and the butoxy ethanol ester of 2,4–D with neburon appeared to result in a slightly more rapid killing action rather than effect the end results. The low dry weight of weeds on the untreated check is due to clipping the samples just 16 days after treatment or before the tartary buckwheat had time to make appreciable growth.

Wild buckwheat 1957 trials. Data from post-emergence spraying of wild buckwheat in a crop of wheat and oats are presented in Table 3. Neburon at all rates and at either date gave complete kills

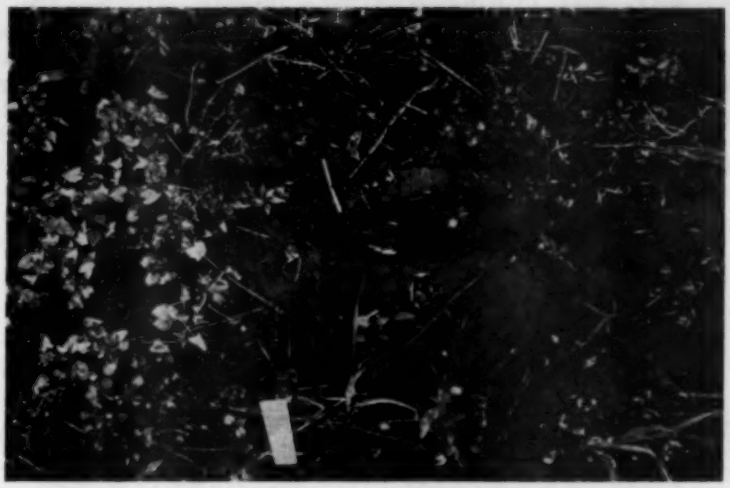

Figure 1. Note complete kill of tartary buckwheat, right of stake, following treatment with neburon at 2 pounds per acre. Plot on left was not treated. White cockle *Lychnis alba* was only slightly injured by this treatment.

of wild buckwheat. However, the yields of wheat and oats were comparable to the check with the exception that the 6 pound rate reduced the oat yield by 3 bushels per acre. The butyl ester of 2,4–D and the butoxy ethanol ester of 2,4–D at 5 ounces per acre resulted in only partial elimination of the weed while two 5 ounces per acre applications gave upwards of 90 percent kills for both herbicides. The butoxy ethanol ester of 2,4–D as a double application adversely affected the yields of wheat at each date while the butyl ester of

Table 3. Estimated kill of wild buckwheat and yields of wheat and oats following treatment with phenoxy herbicides and neburon, Scott, Saskatchewan, 1957.

Herbicide	Rates per acre	Dates of application	Pct. kill of buckwheat	Yield bu/A	
				Wheat	Oats
2,4–D ester	5 oz.	2–4 leaf	84	14.9	24.8
2,4–D ester	5 oz.	3–5 leaf	61	14.6	—
2,4–D ester	5 oz. + 5 oz.	2–4 leaf	91	15.8	23.5
2,4–D ester	5 oz. + 5 oz.	3–5 leaf	69	13.6	—
2,4–DLV ester[a]	5 oz.	2–4 leaf	88	16.0	23.4
2,4–DLV ester	5 oz.	3–5 leaf	51	17.7	—
2,4–DLV ester	5 oz. + 5 oz.	2–4 leaf	94	13.9	21.3
2,4–DLV ester	5 oz. + 5 oz.	3–5 leaf	90	12.5	—
Neburon	4 lbs.	2–4 leaf	100	14.2	24.3
Neburon	4 lbs.	3–5 leaf	100	15.3	—
Neburon	6 lbs.	2–4 leaf	100	15.2	19.8
Neburon	6 lbs.	3–5 leaf	100	14.8	—
Check	—	—	—	15.8	22.8

[a]Refers to the butoxy ethanol ester of 2,4–D.

2,4–D reduced the yield of wheat only when a double application was made at the 3- to 5-leaf stage.

In Table 4, the percentage kill of wild buckwheat is given for different amounts of neburon in 100 gallons of water per acre. It will be noted that rates of 2 pounds per acre or higher gave 100 percent kill of wild buckwheat. The 0.5 and 1.0 pound per acre dosages killed the tops of the plants but gave no reduction in the stand of wild buckwheat. This test was conducted on an area seeded down to Fairway crested wheat grass. The 8 pound per acre rate caused chlorosis on the young grass seedlings whereas the lower rates had no visible effect on the grass.

Table 4. Estimated kill of wild buckwheat with varying rates of neburon, Scott, Saskatchewan, 1957.

Neburon lb/A	Pct. kill of buckwheat	Remarks
0.5	Nil	Tops killed
1.0	Nil	Tops killed
2.0	100	—
3.0	100	—
4.0	100	—
6.0	100	—
8.0	100	—

Table 5 showed that the volume of water used as a diluent had no effect under the conditions of this trial. This same result was seen in Table 2. The treatments with the 2,4–D esters controlled the other weeds, whereas neburon alone had no effect on them. The mixing of the butyl ester of 2,4–D or the butoxy ethanol ester of 2,4–D with the neburon, appeared to result in a more rapid kill of wild buckwheat.

Table 5. Estimated kill of wild buckwheat following treatments with neburon applied in varying volumes of water, Scott, 1957.

Treatment			Rate water gal/A	Percentage kill of weeds		
Neburon lb/A	Additive	oz/A		Buck-wheat	Lamb's quarters	Russian thistle
3	None		100	100	0	0
4	None		100	100	0	0
3	None		170	100	0	0
4	None		170	100	0	0
3	None		230	100	0	0
4	None		230	100	0	0
3	None		285	100	0	0
4	None		285	100	0	0
3	2,4–D ester	5	100	100	100	100
4	2,4–D ester	5	100	100	100	100
3	2,4–DLV ester[a]	5	100	100	100	100
4	2,4–DLV ester	5	100	100	100	100

[a]The butoxy ethanol ester of 2,4–D.

Discussion

The experimental evidence procured from these trials has shown that neburon can be used as a selective herbicide for the post-emergence control of either tartary or wild buckwheat in cereal

crops. The significant feature in favor of neburon over herbicides such as the butyl ester of MCPA was that it completely destroyed the plants, whereas the phenoxy-type herbicides result in a limited suppression of growth and seed setting (3, 4, 5, 8, 9). This latter aspect is of particular importance with tartary buckwheat, since its seeds are not tolerated in seed grain and only a very limited tolerance is permitted in the commercial grades of grain. A number of common species of annual weeds such as stinkweed, lady's thumb, lamb's quarters, Russian pigweed and Russian thistle were tolerant to post-emergence treatment with neburon. The butyl ester of 2,4–D, the butoxy ethanol ester of 2,4–D and butyl ester of MCPA each at 5 ounces per acre mixed readily with neburon. While the mixtures had no apparent effect on the degree of control they appeared to result in a more rapid killing of the buckwheat. Moreover they did afford a good measure of control of the weed species noted to be tolerant to neburon used alone.

The data presented indicate that tartary buckwheat was more readily killed when treated during the early seedling stage. The trials conducted in 1956 and 1957 point to the need for treating tartary buckwheat not later than the 4-true leaf stage. The trials carried out on wild buckwheat in 1957 and given in Table 5 suggest that spraying could be delayed slightly longer with equally good results. The rate of application necessary for complete kills under the varied conditions sampled in these trials was 3 pounds per acre of active ingredient. Under conditions of ample moisture for growth and with treatment made prior to the 4-true leaf stage the rate of neburon could be reduced to 2 pounds per acre.

Cereal grains treated prior to the 6-leaf stage appeared to be unharmed by post-emergence treatment with neburon at dosages as high as 4 pounds per acre. The tolerance of the grain is therefore well above the dosage of neburon indicated for effective buckwheat control. This is a further advantage over the butyl ester of 2,4–D and the butoxy ethanol ester of 2,4–D when applied to grain crops at the time and rate seemingly required for control of either tartary or wild buckwheat. Where neburon was applied at 6 pounds per acre and higher rather severe damage was noted with wheat, oats and barley. Information on the effect of neburon applied at later stages of development was not obtained.

These trials indicate that neburon is the best chemical to appear to date for the control of tartary and wild buckwheat. However, in its present form of 18.5 percent wettable powder requiring large volumes of water for uniform coverage, neburon is entirely unsuited for field scale applications in western Canada. Its cost may also be a limiting factor and unless it is scaled to a level competitive with the phenoxy-type herbicides, the latter will likely be used for the control of the buckwheats even though they are not as effective.

SUMMARY

Post-emergence applications of neburon permitted the selective control of tartary and wild buckwheat in cereal grains. Complete

kills of either species of buckwheat without injury to wheat, oats or barley were consistently obtained with not less than 3 pounds per acre of neburon applied at or prior to the 6-leaf stage of the weed and the grain. Under conditions of ample moisture and with treatment made prior to the 4-leaf stage of growth of the weed, highly satisfactory results were realized from the use of neburon at 2 pounds per acre. Large volumes of water, approximately 100 gallons per acre, were required for uniform application. This would constitute a most serious problem to its practical use on grain farms which have equipment adapted only for low volume spraying of 2,4–D. The possible high cost of neburon would be a further deterrent to its farm use.

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Effects of Light Quality on Herbicide Toxicity to Plants[1]

SUBHASH C. DATTA and STUART DUNN[2]

THE purpose of this study was to find more information on how and why certain herbicides act as they do on plants. The need for this kind of basic fact finding is often emphasized (1, 5, 6, 8). One approach to this problem is to study the effects of various environmental factors on herbicide behavior with plants. An effective way is to hold certain factors constant and alter the amounts or qualities of one or more other factors. Previous work with various colored fluorescent lights (4, 7) had shown marked differences in plant response to various portions of the visible light spectrum. Using essentially the same technique, this study was made of the influence of light quality in modifying the herbicidal effect of 2,4–dichlorophenoxyacetic acid (hereafter called 2,4–D) as various salts and esters. The combined herbicide—light effect was measured principally by dry weight variations from those of normal (control) plants.

MATERIALS AND METHODS

The chief features of the constant temperature room and the types of fluorescent lamps used have been described previously (4). At first, several different preliminary experiments were necessary to establish standard procedures. The results of these have been given in two progress reports (2, 3). The methods based on these findings and followed in the present work are described briefly as follows:

Mustard as a weed and tomato as a crop plant were chosen because they are both very sensitive to 2,4–D. Seedlings of each were grown in plastic containers (10 cm square by 6 cm deep, so-called ice-box dishes) filled with vermiculite, and supplied at intervals with a standard nutrient solution. These were kept in the greenhouse for about 17 days. Six days after sowing they were large enough to be thinned to 20 plants per container. After they were well established in the greenhouse, the plants were placed on rotating tables under lights of different colors in the air-conditioned room. The photoperiod found suitable for maintaining mustard in the vegetative stage, in which its response to the herbicide was most uniform, was 16 hours of light alternating with 8 hours of darkness. The temperature was maintained at 70° F during the time lights were on, and at

[1]Published with the approval of the Director of the New Hampshire Agricultural Experiment Station as Scientific Contribution No. 218.

This study was part of Northeast Regional Project NE–12, "Influence of Environmental Factors on the Effectiveness of Herbicides"; a cooperative study involving agricultural experiment stations in the Northeastern Region and supported in part by regional funds.

This paper is based upon a thesis prepared by the senior author in partial fulfillment of the requirements for the Ph.D. degree at the University of New Hampshire.

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60° F while they were turned off. After a standard conditioning period under the lights, representative numbers of plants were treated with one or another of the different salts or esters of 2,4–D. These were applied as sprays on the foliage and such application was always done outside the control chamber. These plants were then returned to their positions under the lamps where they remained, along with untreated controls, for a further developing effect (post-spray period). The total time under light for mustard was 30 days, including 20 days conditioning and 10 days post-spray period. The time for tomato seedlings was 12 days, consisting of 7 days conditioning and 5 days post-spray period, with one exception. This was an experiment with the ammonium salt of 2,4–D involving the longer period of 30 days, the same as that for mustard.

Other findings in these progress reports (2, 3) which have a bearing on procedures used were as follows: A series of experiments on the effect of the age of the plant showed that this made no particular difference in the relative degree of effect of 2,4–D on dry weight compared to untreated controls. Gradual increases in concentration of 2,4–D applied to the plants produced corresponding increases in injury as shown by decreased dry weight yields. Two concentrations, 1000 ppm and 5000 ppm (parts per million), were chosen as being fairly indicative of the maximum effect without resulting in overdosage.

Salts and esters of 2,4–D tested on mustard were: The sodium salt, ammonium salt, methyl ester, ethyl ester, isopropyl ester, and alkanolamines.[3] With the exception of the ethyl ester and the isopropyl ester, the same materials were used on tomato seedlings.

Some untreated control plants were harvested at the beginning and some at the end of the light conditioning period. Some of both treated and untreated plants grown under identical conditions were harvested at the end of the post-spray period. The fresh and dry weights of the plants harvested at the start of the conditioning period were in each experiment subtracted from the corresponding harvest weights recorded thereafter. These latter, therefore, represent levels of performance exclusively under the experimental lights.

The lamps used in these experiments were all General Electric 96-inch T–8 slimline fluorescent, arranged 6 per luminaire. The colored lamps were blue, green, yellow (gold), pink and red. The effects of the light from each of these was compared with that of a standard "white" lamp known as Warm White. Whether or not the use of warm white light as a standard of comparison was fair or desirable may be debated. However, early experiments of a preliminary nature had shown that the variations of intensity, day length, and temperature effects of natural daylight made it an unreliable standard (4). All of the lamps were commercially available except the red lamps, which were made in the laboratory of the General Electric Co. especially for use in this study. The latter were

[3]Commercial preparation of 2,4–D Dow Weed Killer Formula 40, active ingredients; alkanolamine salts (of the ethanol and isopropanol series) of 2,4–D, 65 percent.

considerably higher in intensity than the commercial red lamps. The spectral emission curves for each of the lamps are presented in Figure 1. It can be seen from this that the light from the various colored lamps represents the principal portions of the visible spectrum of light. There was some overlapping of spectral emission by

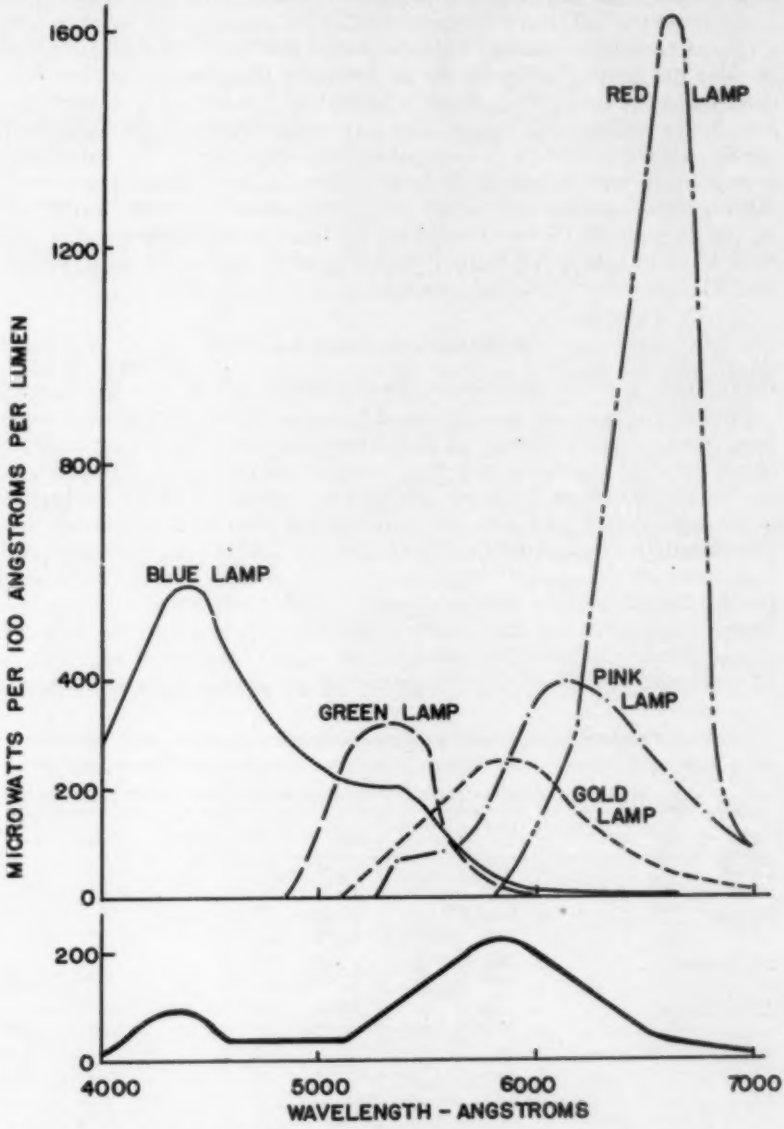

Figure 1. Spectral emission curves for fluorescent lamps. *Top*—colored lamps. *Bottom*—warm white lamps.

some of the lamps, notably in the green, yellow and pink. However, the curves for red and blue are rather separate and distinct from each other.

Because the maximum light intensities obtainable with some of the colored lamps were relatively low, most of these experiments were performed with fairly low light intensities. In this way, equal intensities for all wave lengths could be maintained within any series of tests. This was as high as about 500 foot candles for some, and for others might be set for an intensity down to about 300 foot candles. All experiments here reported were carried out with the intensities within this range. For any single experiment, involving the five different colors in comparison to white light, the intensities were all adjusted to within 10 foot candles of each other. These were the corrected intensities, which were the meter readings multiplied by the correction factors furnished by the General Electric Co., for each kind of lamp. All light intensities were measured with a General Electric Multi-cell light meter.

RESULTS AND DISCUSSION

Reduction in dry weight yields by herbicide action.

One of the ways of presenting the results is to tabulate and compare the actual amounts of reduction in yield of treated plants below that of the corresponding control plants. This reduction in dry weight is one of the most precise measurements of the herbicidal effect, and any decrease in this value below that of the controls may be regarded as an adverse effect due to 2,4–D. It represents the difference in dry weight between the untreated control plants and the herbicide treated plants growing under the same light conditions. A summary of the results with mustard is given in Table 1. These results represent the averages of the dry weights of plants from 12 containers, each of which contained 20 plants. The significance

Table 1. Decrease in dry weights of mustard below corresponding controls.

2,4–D preparation applied	2,4–D conc. ppm	Reductions in dry weights under various lamps—mgm[a]					
		Warm white	Blue	Green	Yellow	Pink	Red
Na salt	1000	76	205**	37	52	128**	322**
	5000	76	287**	33	72	197**	410**
NH_4 salt	1000	48	195**	18	28	84**	283**
	5000	54	236**	28	38	102**	357**
Methyl ester	1000	58	115**	21	26	144**	276**
	5000	90	175**	23	53	158**	304**
Alkanolamines	1000	71	120**	23	35	148**	178**
	5000	88	186**	25	38	178*	267**
Ethyl ester	1000	39	230**	24	15	116**	200**
	5000	70	265**	39	40	158**	261**
Isopropyl ester	1000	54	212**	20	17	99**	201**
	5000	75	256**	29	50	146**	257**

[a]Comparisons for significance were with the value obtained with warm white light.

of each yield reduction figure (reduction below that of untreated controls), for the plants under the colored lamps was calculated by simple T test in comparison with that under warm white lamps as a standard. For comparative purposes the increases in dry weights of control plants appear in Table 2. These plants did not receive herbicide treatment but were grown simultaneously with the plants

Table 2. Increase in dry weights of mustard control plants.

Control plants grown simultaneously with the following treatments	Increase in dry weight during 30-day light period under various lamps—mgm					
	Warm white	Blue	Green	Yellow	Pink	Red
Na salt	175	485	85	155	345	665
NH_4 salt	125	360	55	67	211	453
Methyl ester Alkanolamines[a]	175	358	34	83	291	450
Ethyl ester Isopropyl ester[a]	158	400	66	105	286	523

[a]A single set of controls served for each of these pairs of treatments.

treated with the chemicals indicated in the left column. The dry weights of the plants harvested at the time of placing the remainder under the artificial lights varied between 25 and 39 milligrams.

On a similar basis the results for tomato plants are given in Tables 3 and 4. For two of the compounds, the methyl ester and alkanolamines of 2,4–D, a test was omitted under three of the light qualities with tomato. These were the blue, yellow and pink. However, the results in the experiments with those compounds where there was complete coverage of the spectrum were very consistent with those involving only the warm white, green and red lights.

Figure 2 represents a fairly typical graph of the general pattern of response to the combined effects of light quality and herbicide. Results are arranged in the order in which the light from the various lamps occurs in the spectrum. The reduction in yield is shown by

Table 3. Decrease in dry weights of tomato below corresponding controls.

2,4–D preparation applied	2,4–D conc. ppm	Reductions in dry weights under various lamps—mgm[a]					
		Warm white	Blue	Green	Yellow	Pink	Red
		Total light period 12 days					
Na salt	1000	37	73**	19	19	63**	87**
	5000	40	104**	28	23	64*	148**
NH_4 salt	1000	24	54**	13	9	35	207**
	5000	28	55*	14	12	40*	218**
Methyl ester	1000	31	—	5	—	—	161**
	5000	35	—	16	—	—	148**
Alkanolamines	1000	31	—	19	—	—	111**
	5000	37	—	31	—	—	154**
		Total light period 30 days					
NH_4 salt	1000	68	392**	39	48	165**	519**
	5000	82	436**	71	68	189**	649**

[a]Comparisons for significance were with the valve obtained with warm white light.

Table 4. Increase in dry weights of tomato control plants.

Control plants grown simultaneously with the following treatments	Increase in dry weight under various lamps—mgm					
	Warm white	Blue	Green	Yellow	Pink	Red
	Grown for 12 days					
Na salt	93	307	55	92	209	305
NH_4 salt	100	143	41	33	112	451
Methyl ester	109	—	40	—	—	401
Alkanolamines	113	—	42	—	—	356
	Grown for 30 days					
NH_4 salt	282	878	176	197	480	1009

the height of the columns and the width of each column has no other significance than to show the extent of the major light emission of each lamp.

This graph shows in striking fashion that under red and blue light there was a pronounced reduction in dry weight yield. The same was true of the reduction under pink light to a somewhat less extent. A comparison to the graph for light emission in Figure 1 shows that the light from the pink lamps contained both yellow and red parts of the spectrum. From this it may be assumed that the pronounced effect of the pink light was due to the red light in its make up. On

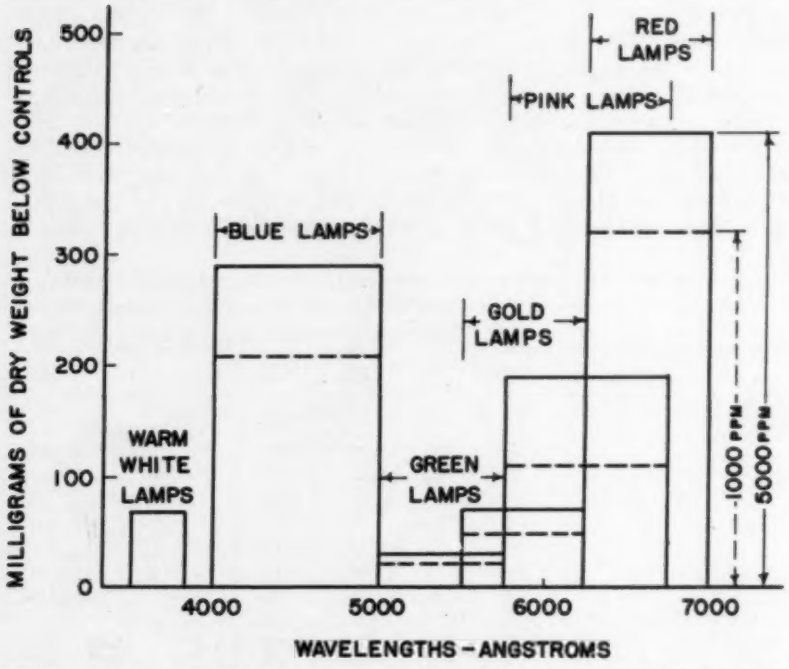

Figure 2. Dry weight reduction of mustard below that of corresponding controls by the sodium salt of 2,4–D, as modified by light quality.

the other hand the effects of yellow and green light were much less. The effect of yellow light is very nearly the same as that for warm white. This is not surprising in view of the close similarity of the contours of the major light emission for the two lamps. In emission of the green lamps, however, there was almost total absence of red and blue light, which may help to account for the fact that the reduction response under green light was always markedly less than that under warm white (Table 1). Here, it may be pointed out that the effects of the two concentrations of 2,4–D, 1000 and 5000 ppm, were the same for the data on warm white light in Figure 2 and thus there is no separate line for the lower concentration in the warm white column.

A further point of interest is the marked resemblance in the pattern of response for that of reduction by 2,4–D to that for increase in dry weight in photosynthesis (7) and that for growth of lettuce (4) under these same kinds of lamps. The contours of a graph of an absorption spectrum of chlorophyll also show high "peaks" in the blue and red. All this lends further support to the earlier suggestion (2), that one effect of 2,4–D on plants may be an interference with, or an inhibition of that process.

The comparative effects of several different compounds of 2,4–D, as summarized in Tables 1 and 3, were consistently alike throughout in the general pattern of response. The reductions in yield caused by all the compounds on both mustard and tomato under the red and blue portions of the spectrum showed high significance (1 percent level) in comparison to those under warm white, with one exception. That was for the blue light in a test with the ammonium salt of 2,4–D on tomato at the higher concentration. It was significant only at the 5 percent level. The reductions in yield under the pink lamps were somewhat less than those under blue and red, but still highly significant in comparison to those under warm white in several instances, especially with mustard.

The influence of increase in concentration of 2,4–D (5000 over 1000 ppm) was chiefly to accentuate further the effects of red and blue light, which even at the lower concentrations produced a marked effect. The response was much less with tomato in the shorter light treatments (12 days) than with mustard over a greater interval of time (30 days). However, in the one instance where the tomato plants were given the longer treatment (with the ammonium salt) the extent of reduction in yield by the higher concentration was very similar to that of mustard.

Reduction in yield by herbicide as percent of increase of controls.

Another way of presenting the results is to show the relation of reduction by 2,4–D effect to increases of controls as a ratio between the two, or the reduction as a percent of the other. This may be done on two bases. One is to calculate each reduction as a percent of the increase in dry weight of corresponding controls during the entire light period; 30 days for mustard and one test with tomato, and 12 days for each of the other series with tomato. This was done

by calculating the percentages of the individual weights and averaging them. In this way the significance of the averages for the different colors could be calculated as compared to the averages of the percentages from warm white as a standard. The results on this basis for mustard and tomato are given in Tables 5 and 6 respectively.

The other basis is to express the individual reductions as percentages of the increases in dry weights of controls during the post-spray period only; 10 days for mustard and one group of tomato, and 5 days for the other tomato plants. These have been compiled in Table 7 for mustard and in Table 8 for tomato.

Table 5. Reductions in dry weight of mustard by 2,4–D as per cent of increase of controls during total light period.

2,4–D preparation applied	2,4–D conc. ppm	Relation of (a) decrease by 2,4–D to (b) increase in controls for 30 days under various lamps—percent[a]					
		Warm white	Blue	Green	Yellow	Pink	Red
Na salt	1000	38	43	26	30	36	48*
	5000	40	61**	33	44	57**	62**
NH_4 salt	1000	39	53**	32	43	41	57**
	5000	42	65**	50*	57**	48*	77**
Methyl ester	1000	31	35	72**	30	45*	58**
	5000	57	49	78*	44	51	66*
Alkanolamines	1000	40	33	73**	44	48	52**
	5000	54	55	79**	45	58	62
Ethyl ester	1000	42	61**	28	15	36	39
	5000	56	71**	49	34	47	50
Isopropyl ester	1000	49	57**	29	16	32	37
	5000	58	68**	39	30	48	49

[a]Comparisons for significance were with the value obtained with warm white light.

Table 6. Reductions in dry weight of tomato by 2,4–D as percent of increase of controls during total light period.

2,4–D preparation applied	2,4–D conc. ppm	Relation of (a) decrease by 2,4–D to (b) increase in controls under various lamps—percent[a]					
		Warm white	Blue	Green	Yellow	Pink	Red
		Grown for 12 days					
Na salt	1000	41	24	36	20	29	31
	5000	45	33	56*	23	35	49
NH_4 salt	1000	24	37**	33	29	30	46**
	5000	29	48*	33	35	60**	49**
Methyl ester	1000	28	—	11	—	—	39**
	5000	35	—	35	—	—	41**
Alkanolamines	1000	27	—	42*	—	—	27
	5000	33	—	59**	—	—	43**
		Grown for 30 days					
NH_4 salt	1000	27	46**	28	24	33	53**
	5000	23	50**	13	38*	36**	113**

[a]Comparisons for significance were with the value obtained with warm white light.

An examination of these tables of percentages reveals somewhat of a shift in emphasis to the effects of green light. The size of percentage reduction under green with mustard is greater by high

Table 7. Reductions in dry weight of mustard by 2,4–D as percent of increase by controls during post-spray period.

2,4–D preparation applied	2,4–D conc. ppm	Relation of (a) decrease by 2,4–D to (b) increase in controls for 10 days under various lights—percent[a]					
		Warm white	Blue	Green	Yellow	Pink	Red
Na salt	1000	62	77	50	48	61	86**
	5000	65	108**	65	71	96**	110**
NH_4 salt	1000	60	86**	54	62	61	105**
	5000	65	105**	82*	83**	73	139**
Methyl ester	1000	64	225**	187**	56	83	117**
	5000	124	420	208*	80	99	130
Alkanolamines	1000	74	270*	208**	84	91**	94
	5000	113	450**	225**	84	125	125
Ethyl ester	1000	64	115**	52	37	92**	154**
	5000	87	129**	93	84	125**	200**
Isopropyl ester	1000	84	106**	54	33	86	140**
	5000	92	118**	73	71	134*	185**

[a]Comparisons for significance were with the value obtained with warm white light.

Table 8. Reductions in dry weight of tomato by 2,4–D as percent of increase by controls during post-spray period.

2,4–D preparation applied	2,4–D conc. ppm	Relation of (a) decrease by 2,4–D to (b) increase in controls under various lights—percent[a]					
		Warm white	Blue	Green	Yellow	Pink	Red
		Grown for 5 days					
Na salt	1000	62	55	62	32	66	70
	5000	70	79	97**	37	84	110**
NH_4 salt	1000	36	63**	56	36	32	72**
	5000	43	65**	86**	44	60*	76**
Methyl ester	1000	40	—	17	—	—	67**
	5000	51	—	49	—	—	70**
Alkanolamines	1000	47	—	52	—	—	52*
	5000	54	—	87**	—	—	79**
		Grown for 10 days					
NH_4 salt	1000	92	86	106	51	53	123*
	5000	76	94	27	69	61	151**

[a]Comparisons for significance were with the value obtained with warm white light.

significance than that for warm white for two of the compounds, methyl ester and the alkanolamines. There is agreement with this for the latter compound on tomato, but more of a scattered significance of the results under green light with other compounds on this plant. This accentuation of the effect of green light on this basis of mathematical presentation is due chiefly to the fact that while the

reductions in dry weight under green light were small, the increases in dry weight of the controls were also small.

Another fact that emerges from a consideration of these tables is that there is still shown a highly adverse effect of 2,4–D on plants under red light and to a somewhat less extent under blue light, especially with mustard. The effects of the pink light were much less and the significant values more scattered than on the basis of actual weight reductions. Perhaps this was due to the considerable amount of yellow light in its make up.

SUMMARY

Mustard and tomato seedlings were grown under various light qualities at a constant higher temperature for light and a lower one for darkness. After a conditioning period to light, herbicide was applied to some of the plants. Harvest for dry weights was made after a further light exposure, along with untreated controls under similar conditions.

For several different compounds of 2,4–D at two concentrations, and for both types of plants, the pattern of response was very similar. This was measured as the reduction in dry weight yield in herbicide treated plants below that of controls under the same lights. The responses under colored lights (blue, green, yellow, pink, and red) were each compared to that under a standard white lamp (warm white). The reductions in yield were significantly greater with red, blue, and to some extent pink, than those for warm white. The effects of the other colors were much smaller. The general pattern of size of reduction in yield in various portions of the visible spectrum was very similar to the pattern of dry weight yield for photosynthesis. This suggests an interference in that process by the herbicide.

When the reductions in dry weight by herbicidal action were expressed as percentages of increases in corresponding controls, a somewhat different pattern of response emerged. For two compounds, especially, there was a shift to greater significance for the effects of green light. This was due, in part at least, to the relatively small amount of increase in dry weight by the controls themselves under this light. However, the effects of red and blue light in enhancing 2,4–D action were still consistently large on this basis of presentation.

ACKNOWLEDGEMENT

The authors wish to express thanks to the General Electric Company, and particularly to J. P. Ditchman, of that company, for supplying certain lamps and other materials used in these investigations, as well as advice and information.

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A Method of Comparing Herbicides and Assessing Herbicide Mixtures at the Screening Level[1]

DONALD P. GOWING[2]

A VERY useful technique in toxicological investigation is probit analysis. This method, which was developed by Bliss and other workers (notably Gaddum and Finney, but see reference 4, pp. 42–46) consists of plotting the log concentration of a toxicant against the percentage response on a probability scale, and fitting a weighted regression line to the data. Although the technique has found wide application in pharmacology, entomology, and plant pathology, it has been almost ignored by workers in herbicide research. It is the purpose of this paper to demonstrate that the concepts of probit analysis are applicable to herbicide research, and that the mere plotting of data on logarithmic probability paper may permit a very fruitful interpretation of experimental results. The technique is recommended at the screening level, for its results are very useful in the construction of field tests. It is in no sense a substitute for the carefully designed and executed field test, or for the analysis of test results by other statistical techniques.

In general, herbicides received in quantity sufficient for field testing have already undergone preliminary survey by the manufacturer. Rates for satisfactory use are regularly suggested, but many materials, when used at these rates, fall far short of a satisfactory performance in comparisons with other materials. When rates for subsequent comparative tests are selected on any empirical grounds, progress is often slow, and expense of testing then becomes unjustifiably high for the information gained. Actually, it is an important principle of toxicological experimentation that the question, "How much toxicant is required to produce a given level of response?" can be much more accurately answered than the question, "How much response is obtained from a given level of toxicant?" Most field tests, and indeed most tests reported in herbicide literature, have asked the second of these questions. Moreover, most investigators conduct their tests with the very practical object of obtaining the maximum kill. This in fact reduces the validity of *comparisons* of herbicides because much more accurate information can be obtained about a toxicant if it is investigated near the 50% level of its effectiveness. The 50% level is more reliable than higher or lower toxicities because the response to herbicides is generally non-linear with respect to dose. Equal increments of dose do not generally produce equal increments of response over the entire response range, and the tendency to disproportionality is minimized in the middle range. Given non-linear data, a substantial advance in predictability of results at the limits of response may be obtained if

[1]Published with the approval of the Director as Technical Paper 251, Pineapple Research Institute of Hawaii, Honolulu, Hawaii.

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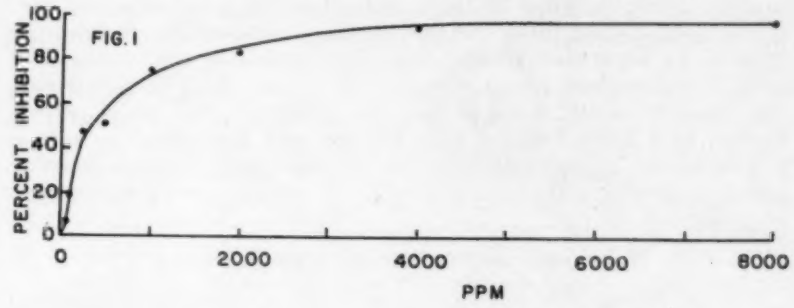
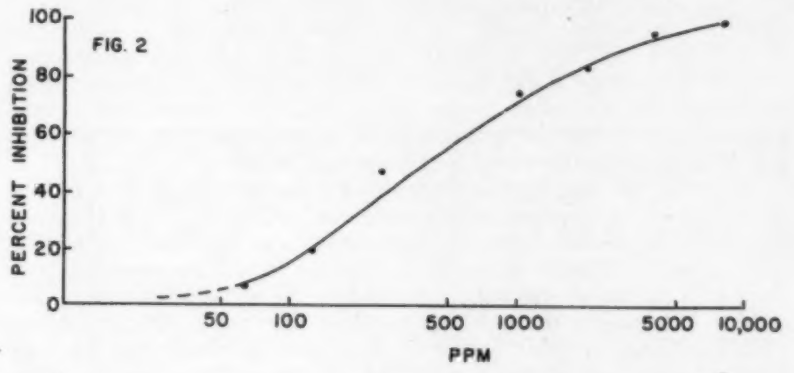
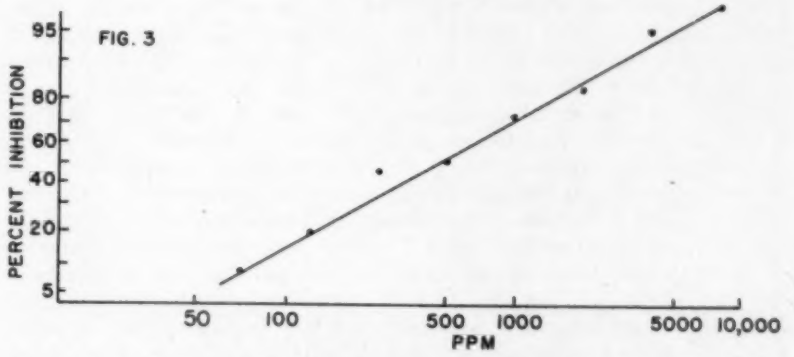
extrapolation can be made from such data transformed to a straight line graph.

Let us start with the observation that if one were to plot the percent toxicity against the range of doses of a toxicant, the graph would be sigmoid (S-shaped) but not symmetrical (Figure 1). The absorption of a toxicant apparently follows, in a number of cases,







Figures 1, 2, 3. Percent inhibition of growth of sunflower seedlings dipped into solutions of sodium trichlorobenzoate. *Figure 1,* arithmetic plot. *Figure 2,* plot of percent inhibition of growth vs. log dose. *Figure 3,* (probit of) percent inhibition vs. log dose. The "dosage-response line."

an exponential relationship (2). Consequently, if percent toxicity is plotted against the *logarithm* of the dose, the skew sigmoid is often transformed to a more symmetrical sigmoid (Figure 2). And another useful principle is that the validity of the measurement of the response often varies with the magnitude of the response in a (statistically) "normal" fashion. That is, the measurement is a more probable statement of the true response in the middle response range than at either extreme. If, then, instead of the untransformed percent response, one plots the percent in a probability distribution against the logarithm of the dose, the sigmoid curve of Figure 2 may be transformed into a straight line (Figure 3). The plot is very conveniently made if log-probability paper is used to start (e.g. Keuffel and Esser No. 358–22). The straight line which results is known as the "dosage-response line" (5), and has a number of interesting properties, the investigation of which constitutes probit analysis.

PROPERTIES OF THE DOSAGE-RESPONSE LINE

For one thing, this line may provide an answer to the question "If this much herbicide gave this percent kill, how good would twice as much have been?" If the slope of the line is steep, the chances are that the herbicide would have given a satisfactory return; if the slope is flat, more herbicide would have been but little more effective. Or, more to the point, since the vertical axis is now a probability scale, the graph can be used to predict within odds just how much better more herbicide will be (6).

Secondly, the steepness of the line has been related to the standard deviation of the response, a very steep line indicating a low standard deviation. And since different characteristics of the same population usually have different standard deviations, it will be seen that two chemicals (tested at the same time and in the same way) which have different slopes for their dosage-response lines have different standard deviations for their toxicities. It is then inferred that they are affecting different characteristics of the population, or in other words, that they have different modes of action. This generalization has recently been called into question by McCallan (7). Third, some compounds may be toxic more ways than one, and thus give a "broken" or non-linear dosage-response line (cf. curves for PCP or 2,4–D, Figure 6). Fourth, as noted earlier, the reliability of the measurement of the response is at a maximum for samples near the 50 percent point on the statistically normal response curve. Information obtained at various points along the dosage response line should not be given equal weight, since it is least accurate near the extremes of the response. Fifth, if two such lines are parallel, the potencies of the two chemicals can be directly compared, since parallel lines indicate similar standard deviations for the responses (this is sometimes taken as permissive, but not definitive, evidence of a similar mode of action). However, if two chemicals give dosage-response lines which are not parallel, then it may happen that the lines will cross on the graph. The conclusion as to which is the more potent

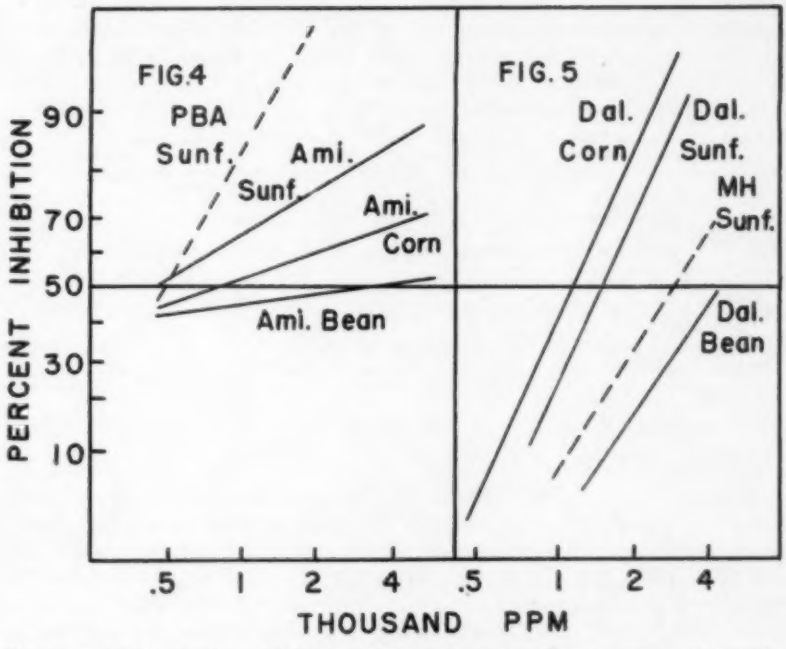
will vary according to what dosages are tested and at what level the response is to be measured.

G. E. Blackman and his co-workers, Simon and Sampford (1, 8, 9, 10) at the University in Oxford, England, have published an important series of papers on the principles of phytotoxicity, and have applied the methods of probit analysis to herbicidal investigations, but mostly with reference to quantal responses (all-or-none responses). Some of their observations on the behavior of the dosage-response line may be summarized, and in part illustrated with the quantitative data obtained by the writer:

1. Different plant species vary widely in their susceptibility to different chemicals, and this often leads to different slopes of dosage-response lines for the same chemicals with different species (cf. Figure 4 curves for amitrol or Figure 5 curves for dalapon).

2. Unrelated chemicals can be expected to have non-parallel dosage-response lines when tested on the same plant (cf. Figure 4 curves for PBA and amitrol on sunflower).

3. In general, the mere addition of wetting agents, or hygroscopic agents such as glycerine, or such adjuvants as non-toxic oils, often shifts the line to the left or right on the graph without altering its slope. Sometimes, however, the slope may change under these conditions, if, for instance, the dosage-response relationship is non-linear for the toxicant used alone.



Figures 4 and 5. Percent inhibition of growth of sunflower, corn, and garden bean seedlings dipped into solutions of various herbicides.

4. The slope may decrease with increasing age of test plants, because the standard deviation of the assay increases, in general, in tests with older plants.

MATERIALS AND METHODS

Soybean, bean, corn, or sunflower seeds were soaked about 40 hours before planting five seeds per 8 oz. plastic cup in a 3:1 mixture of steam-sterilized loamy soil and vermiculite. Four to five replicates were used to provide 20 to 25 plants per treatment. After 5 to 7 days, plants were treated by dipping foliage into herbicide solutions or suspensions. The range of concentrations (active ingredient basis) shown in the figures was covered in 5 to 9 dosages, spaced logarithmically over the range. Herbicide solutions generally contained 0.5% lauryl sulfate wetting agent and about 0.5% glycerine.

Seven to 10 days later, the plants were harvested and fresh weights of the shoots above the cotyledons were determined. From these was calculated growth as a percent of the controls, and percent inhibition of growth was then plotted against toxicant concentration on log-probability paper.

The herbicides used are listed with their sources in Table 1.

Table 1. Herbicides used, common designations and sources.

Designation	Herbicide	Source
Amitrol	3-amino-1,2,4-triazole	American Chemical Paint Co.
PBA	Sodium trichlorobenzoate, mostly the 2,3,6 isomer. (Formerly Heyden 1281-S)	E. I. DuPont De Nemours Co.
Monuron	3-(*p*-chlorophenyl)-1,1-dimethyl-urea	E. I. DuPont De Nemours Co.
Dalapon	Sodium 2,2-dichloropropionate	Dow Chemical Co.
MH	Maleic hydrazide, diethanolamine salt (MH 30)	Naugatuck Chemical Division, U. S. Rubber Co.
TCA	Sodium trichloroacetate	Dow Chemical Co.
PCP	Sodium pentachlorophenate	Dow Chemical Co.
EBP	Ethyl bis(dibutylamido)phosphate	Pennsalt Mfg. Co. of Washington
CDT	2-chloro-4,6-bis(diethylamino)-*s*-triazine	Geigy Chemical Corp.
2,4-D	2,4-dichlorophenoxyacetic acid, mixed alkylamine salt	Pacific Chemical and Fertilizer Co.

RESULTS

HERBICIDES USED SINGLY.

Figures 6 and 7 show results of tests of certain herbicides on sunflower and soybean. A point of immediate interest is the non-linear dosage-response relationship of 2,4–D and PCP. These compounds are apparently toxic in more ways than one. One would expect that an adjuvant which would improve the penetration of PCP, and thus raise the effective dose, might bring into play the more potent of its toxic mechanisms. This may be a partial basis for the synergistic effect reported for oil emulsions of this material. In regard to 2,4–D,

there was an obvious curvilinearity. It was interesting that both PBA (see Figure 3) and 2,4–D induced a series of similar morphogenic effects which affected the fresh weight of the harvested material. The lowest dosage of 2,4–D generally produced distorted strap-like leaves. A little higher dose induced an unusually long internode, and also some linearity of the leaves. Higher dosages resulted in shortening and swelling of the internodal tissues; still further increases severely stunted both internodes and leaves; and the data finally became linear when this result was obtained. The different modes of action, with their different standard deviations, lead to a varying slope and hence to curvilinearity. The progression of these symptoms was not so discrete with regard to PBA, and stunting of the leaves occurred at a lower relative concentration of 2,4–D as compared to PBA. Since the symptoms were intermixed in the plants treated with PBA, the dosage-response for this chemical was more nearly a straight line. (Side effects of both 2,4–D and PBA in non-harvested tissues included brittleness of stems and sometimes splitting of the stem tissue below the cotyledons.)

On the basis of these results, TCA and CDT may be expected to be poor toxicants for foliar application to sunflower.

Compare the lines of Figure 6 with those obtained with soybean seedlings, Figure 7. The high toxicity of monuron at fairly low concentrations was found in both soybean and sunflower. Monuron is usually considered much less effective when applied to foliage than when applied to soil, but in this work was about of the same order of effectiveness as 2,4–D. Dalapon gave a very steep slope in both Figures 6 and 7, but a very high dosage was required. This is validated by the field experience, since this chemical is not usually

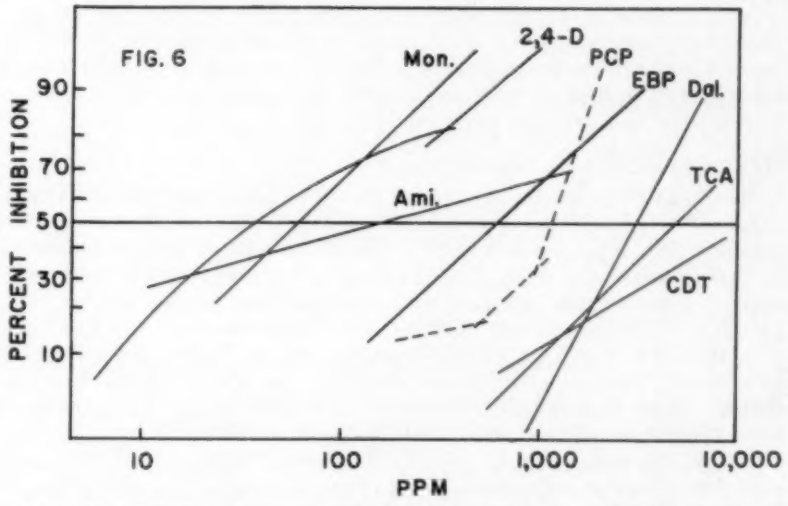


Figure 6. Inhibition of growth of sunflower seedlings dipped into solutions of various herbicides.

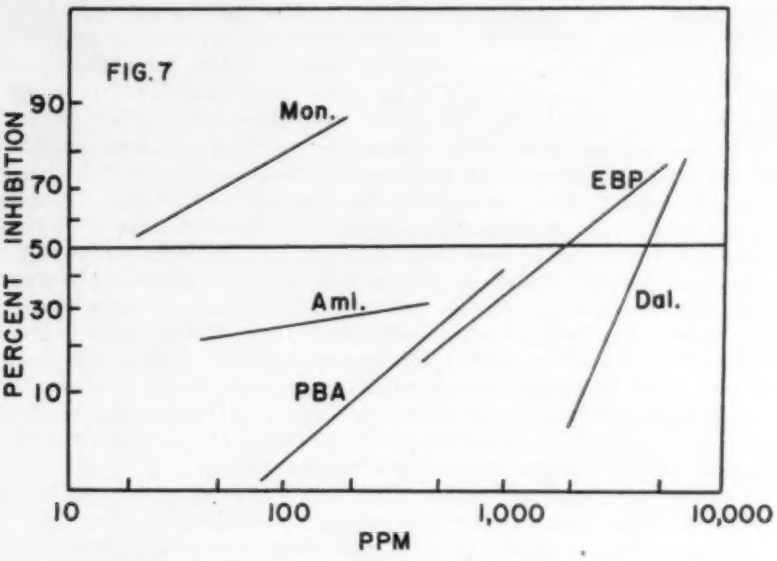


Figure 7. Inhibition of growth of soybean seedlings dipped into solutions of several herbicides.

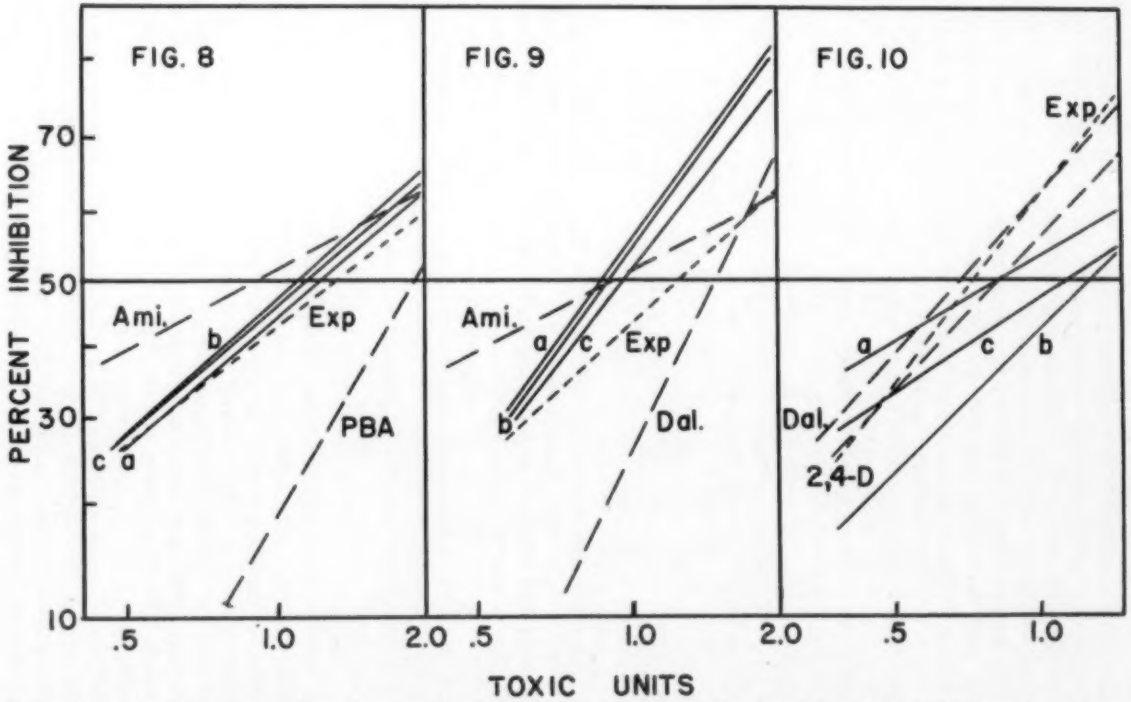
recommended for broadleaf plants. Note the interesting relationship of dalapon to TCA. These are similar chemicals, but their different slopes imply modes of action or quite different rates of penetration, and they have obviously different potencies in foliar application, if high levels of kill are sought.

Amitrol gave a very flat slope on soybean. For better than 50 percent effectiveness, a great deal more would be required. However, since a little amitrol was almost as effective as much more, it might be expected to find its best use in combination with other materials rather than as a primary toxicant.

HERBICIDE MIXTURES.

Based on preliminary work, the level of each chemical which was expected to give 50 percent inhibition of growth was selected as one "toxic unit". This value was adjusted as new evidence accumulated in the course of the work. For the data of Figures 8 and 9, herbicide mixtures were made up with toxic units in the ratios of 1.5:1, 1:1, and 1:1.5. The herbicides and the mixtures were then used at 0.29, 0.44, 0.67, 1.0, and 1.5 total toxic units—a series increasing by multiples of 1.5. The expected result from the 1:1 ratio, on the basis of added probit mortalities (rather than added doses) for chemicals with these dissimilar slopes, is also plotted.

When the results of the mixture of PBA and amitrol are compared to those of the chemicals used alone, at equivalent toxic unit dosage, it is seen that there was no evidence of any response in excess of that expected. However, the results with the mixture of amitrol



Figures 8, 9, 10. Inhibition of growth of sunflower seedlings dipped into solutions of herbicide mixtures. Dash lines —herbicides used alone. Solid lines—mixtures of (a) 1.5:1, or (b) 1:1, or (c) 1:1.5 ratios of the toxic units (Figure 10, ratios were 3:1, 1:1, 1:3). Toxic unit for amitrol—200 ppm; PBA—300 ppm; dalapon—3000 ppm; 2,4–D—50 ppm. Exp—expected response, 1:1 mixture.

and dalapon (Figure 9) are considered to show synergism at all three ratios. In practice, since dalapon has such a steep slope compared to amitrol, one might incline to the higher dalapon lower amitrol combination for higher levels of kill in field work. It happens that synergism in this combination has been recognized in field work for some time, so that this is no new discovery. In confirming the field work, however, the results do illustrate the technique.

There was evidence of antagonism between 2,4–D and dalapon, particularly at the higher levels of response (Figure 10). Here the herbicides were mixed in 3:1, 1:1, or 1:3 ratios of the toxic units. There was also evidence of antagonism of EBP for PCP, although in this case the severe foliar burn occasioned by PCP undoubtedly precluded any opportunity for EBP to act systemically.

Table 2. Interactions between herbicides inhibiting growth of sunflower seedlings.[a]

Additive	Herbicide						
	Dalapon	Monuron	EBP	PCP	2,4–D	PBA	TCA
Amitrol	+	0	0	0	0	0	
Dalapon		0	0		–	0	
Monuron			0	0		0	0
EBP				–		0	0
2,4–D						0	

[a]0 = no interaction; – = antagonism; + = synergism.

In Table 2 are summarized the interactions detected in the course of the experimental work. Each conclusion is based on at least two sets of data. It often happens that, for materials of widely different potencies, the response tends to follow that of the more potent toxicant (4, chap. 8), and the line for a non-synergistic mixture may even rise above that for a toxicant alone. But in this work, in general, results from mixtures of chemicals fell within the bracket of the lines of the two chemicals used alone.

DISCUSSION

Some limitations of the test procedure should be recognized. A longer time between treatment and harvest might lead to different conclusions. However, a longer time would increase variability. And since these were foliar applications, soil treatment would undoubtedly provide for entirely different penetration characteristics and for a different assessment of those materials which are initially effective on roots. The interpretation of the results must be considered thus qualified.

Moreover, it may be reiterated that the procedures described are no substitute for the actual statistical analysis. The data of this survey did parallel some previous field experience, and the log-probit graphs do suggest explanations of some field results, so that the plotting procedure itself can be valuable. Since the conclusions in any case are to be directive rather than final, graphic methods of treating the data are considered to serve a useful purpose at the screening level.

As a point of interest, it may be mentioned that the probit method of transforming a normal sigmoid to a straight line is independent of the source of the data, and hence has a much wider range of applicability than present use would indicate. The statistics have been much more fully worked out for probit analysis of quantal (all-or-none) responses rather than quantitative responses, however. For a more detailed and logically more rigorous treatment, see Finney (4). Special weighting factors should properly be used for quantitative data treated by the probit method, since any measurement of growth of the controls is but an estimate of the population mean and has a variance (4, chap. 10). (In quantal data, the percent kill of the controls is the invariate zero percent).

As a matter of fact, the more precise procedures of Finney or Wilcoxon and co-workers (4, 6, and 12) presently have but limited applicability even to quantal data. The statistical techniques are not completely developed for comparing toxicants having non-parallel dosage-response lines (i.e. different modes of action) at all doses, but it is of course possible to compare their potencies at some selected response level. Actually, one of the advantages of a log-probit plot is that it permits an inference as to whether different modes of toxicity can be expected from different herbicides. On *a priori* grounds, susceptibility (or resistance) of a weed species to two herbicides might be expected to be more closely correlated if they kill in the same manner than if they kill in different ways. One might then expect that treatment of a weed population with mixtures of herbicides that act differently might be more successful than treatment with mixtures of herbicides that act similarly if the combination is not antagonistic. Should the combination show synergism, of course, this would be particularly useful.

Properly speaking, synergism is a response in excess of that which would be obtained from simple summation of the effects of the materials acting alone. However, the term is often, and carelessly, used to describe the effect of a combination which happens to be very good, irrespective of whether the result was truly synergistic. An error sometimes made in good faith is the calculation of the expected effect on the basis of added doses rather than on additive mortalities. The former is applicable to materials which act similarly, but the latter must be used for materials which act independently (4, chap. 8). Again, probit analysis for investigation of synergism is most widely accepted for all-or-none responses in mixtures of compounds which have parallel dosage-response lines, as discussed by Finney (4, chap. 8 and sect. 53) and Sampford (8). The statistical methods for studying interaction in combinations of toxicants having non-parallel dosage-response lines are not completely agreed on, owing both to changing concepts and to redefinitions of terms (3, 11), and probit analysis of quantitative data from such tests is almost wholly unexplored.

Synergistic interaction between particular dosages of two or more materials is admittedly detectable without reliance on probit analysis. However, the usual field tests involving one or two rates of

application often provide little or no information on modes of activity.

Since we are faced with the likelihood that the most useful synergism for practical purposes will be that given by compounds which act dissimilarly—compounds with *different* slopes to their dosage-response lines—the pictorial representation provided by log-probit plots is considered to offer some very valuable clues to combinations of greatest potential value.

SUMMARY

A technique is described for rapid graphical survey of the dosage-response relationships of herbicides. The method involves assessment at the 50 percent toxicity level rather than at the more complete kills which are sought in field work, and utilizes certain concepts of probit analysis. Experimental data are used to demonstrate the utility of log-probability plots in comparisons of herbicides and in detecting interactions between herbicides preliminary to field testing. In tests of various combinations of herbicides, synergistic interaction was detected between dalapon and amitrol, and antagonism between 2,4–D and dalapon, and between EBP and PCP.

ACKNOWLEDGMENT

Grateful acknowledgment is made to Dr. Karl Hamner and the Botany Department, U.C.L.A., for the provision of laboratory and greenhouse facilities during the major portion of this investigation.

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Some Effects of Various Esters of 2,4–Dichlorophenoxyacetic Acid on the Morphological Development of the Strawberry[1]

RONALD W. CAMPBELL[2]

IT has been shown that with proper timing and the correct concentration, 2,4–D sprays can be used to control strawberry runner production (2). Other effects of this chemical upon the strawberry plants have been studied in a general way by Denisen (4) and Carlson (1). However, these effects have not been shown to be related to a specific influence of the chemicals on the morphological development of the strawberry plant. As the 2,4–D compounds used for weed control have exhibited growth regulating properties (3, 7, 10) it seemed likely that certain preparations might have a more unfavorable influence on plant growth than others. Also, since the molecular structure of the various preparations were different, it could be expected that the various preparations might differ in their influence on the developmental processes of the strawberry.

This study was undertaken to relate some of the effects of the molecular structure of 2,4–D compounds to the morphological development of the strawberry. Specifically, the effect of various 2,4–D ester formulations on the time and extent of strawberry root development was studied.

METHODS AND MATERIALS

Blakemore strawberry plants which had been dug the last of October 1952 and stored at 33° F were planted the following March in 1 gallon cans in the greenhouse and provided with conditions favorable for growth. After establishment, and prior to treatment, all but six leaves were removed from each plant in order that the plants would be as uniform as possible initially.

Five 2,4–D esters of varying molecular weight were used to determine if the length and structure of the alcohol portion of the molecule would affect the activty of the ester. These esters were prepared to possess the same 2,4–D acid equivalent and included the methyl, ethyl, butyl, butoxyethanol, and the propylene glycol butyl ether forms. Twenty plants were used for each chemical treatment with each plant receiving 10 milliliters of solution. Each ester was applied at rates of 1 and 4 milligrams per plant thus making a total of ten groups of treated plants. These materials were sprayed over the plants with a hand atomizer on March 6, with the excess being allowed to drop on the soil surface around the plant. A second application was made at these rates on March 24, 18 days after the first application.

The plants were allowed to grow for 60 days following the first treatment after which they were removed from the cans and washed

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carefully. The roots were cut from the crown and, together with the above-ground portion of the plant, were dried to constant weight in an oven at 85° C. Thus, the dry weights of the shoots and roots were obtained.

RESULTS

The spray applications of all of the ester forms produced considerable formative effects on the leaves and petioles of treated plants. All the leaves of the plants receving the first spray applications March 6 at the 1 milligram concentration showed considerable hyponasty. The younger leaves curled considerably more than the older ones; all of the petioles showed some twisting. These hyponastic effects had completely disappeared when the second spray applications were made on March 24, 18 days later. Following the second applications, hyponasty of the leaves and twisting of the petioles as described above were noted. The younger leaves of the plants sprayed with the ethyl and butyl ester forms showed some curling at the end of 18 days indicating the dwarfing effect to be greater than after the first spray application. With the exception of persistence, it was impossible to visually detect any pronounced difference in induced formative effects on the plants treated with the 1 milligram concentrations of the various 2,4–D esters. There were no statistically significant differences between dry weights of roots or shoots of plants receiving the ester sprays or between treated and untreated plants (Table 1).

Table 1. The effects of two applications of 2,4–D esters of varying molecular weight made 18 days apart on growth of the roots and shoots of Blakemore strawberry plants under greenhouse conditions.

2,4–D ester applied	Molecular weight	Actual chemical applied per plant (mgms.)	Average dry weight—grams		Shoot-root ratio
			Shoots	Roots	
Methyl	234	1.0	2.70	1.45	1.86
		4.0	1.63	1.09	1.49
Ethyl	248	1.0	2.65	1.42	1.86
		4.0	1.68	1.14	1.47
Butyl	276	1.0	2.59	1.40	1.85
		4.0	1.90	1.24	1.53
Butoxy ethanol	320	1.0	2.59	1.41	1.84
		4.0	2.08	1.32	1.58
Propylene glycol butyl ether	334	1.0	2.74	1.52	1.80
		4.0	2.24	1.34	1.67
Control	—	—	2.74	1.49	1.84
LSD at 5% level between treatment averages			0.21	0.15	
LSD at 1% level between treatment averages			0.27	0.20	

Malformation of the leaves and petioles of the plants receiving 4 milligrams of the various ester forms was very pronounced. As a result of the first spray application on March 6, hyponasty occurred in all leaves. Many of the younger leaves were severely curled with the leaf margins folded toward the midrib. The petioles were badly

twisted; in some cases the leaves were completely inverted for a few days. A definite dwarfing effect was noted on all sprayed plants. A browning of the margins of some of the leaves was noted. The tips of the leaves were most commonly injured with the browning seldom extending more than ⅜ of an inch from the apex of the leaf. For the most part the necrosis was confined to the serrations of the leaflets. Considerable leaf curvature was still in evidence 18 days after the first spraying although new leaves were being produced and most of the petioles had straightened. In every case, the second spray application made on March 24 at the rate of 4 milligrams per plant produced effects very similar to those caused by the first application. On some plants young leaves which had just emerged from the crown were killed. In general, the injury to both the leaves and petioles was more severe, thus reflecting the increased concentration. The dwarfing effect was pronounced.

The 4 milligram applications produced rather severe injury to the roots. The youngest roots were more susceptible to injury than were older ones. Also, injury was observed to be greatest in the youngest or tip portion of the individual root. Secondary roots were killed back more severely than the primaries. Little growth was noted until 3 weeks after the second spray application. The plants sprayed with either the methyl or ethyl ester formulations appeared to be more severely injured than the plants sprayed with the other ester forms. This is reflected by dry weights of the treated shoots as seen in Table 1.

All of the esters applied at the rate of 4 milligrams per plant significantly decreased the dry weight of the roots and the shoots when compared with the controls.

A comparison of the shoot-root ratios showed that the 4 milligram application of all the esters reduced the average dry weights of the shoots proportionately more than they affected the roots (Table 1). Further, it was noted that, with the exception of the methyl and ethyl esters, the shoot-root ratio increased with the increase in molecular weight of the chemical. Apparently with the rise in molecular weight, the total dwarfing effect became less as indicated by the increase in total dry weight and the growth of the shoots was inhibited less in proportion than the roots. The 1 milligram application appeared to affect the plants less than the heavier concentrations of 4 milligrams of the various esters of 2,4–D, as the shoot-root ratios were far less variable.

DISCUSSION

When the effect of various 2,4–D ester formulations on the vegetative growth of strawberry plants was compared, a direct relationship between toxicity and length of the carbon chain of the alcohol was noted. The short chain esters were more phytotoxic than the esters of higher molecular weight. Evidence of this was the greater formative effects, increased hyponasty and petiolar curvature, as well as decreased dry weight of roots and shoots of the plants sprayed with the short chain esters. It has been suggested by Robbins, Craft

and Raynor (9) that, when a long chain alcohol is used to formulate a 2,4–D ester, the high molecular weight of the alcohol might dilute the toxic group thus causing the compound to be less toxic than one formed from a short chain alcohol.

The increased phytotoxicity of the short chain esters may in part be due to the absorption of the volatile vapors through the stomata. It has been established that in general the greater the molecular weight of the ester, the lower the volatility. Marth and Mitchell (6) have reported the methyl ester of 2,4–D as being the most volatile of a number of ester formulations tested. They found also that the ethyl, butyl and isopropyl esters were more volatile than the esters of higher molecular weight. Mullison (8) exposed tomato, bean and cotton plants to esters of low molecular weight and observed that a number of them were sufficiently volatile to cause decided plant responses. He reported that as the number of carbon atoms in the aliphatic portion of the 2,4–D ester is increased the volatility decreases. He further observed that an alkanolamine salt and the sodium salt of 2,4–D were nonvolatile, as indicated by responses of exposed plants.

It was noted in these experiments that with the exception of the propylene glycol butyl ether treatment at 1 milligram, all of the esters used reduced the dry weight of the roots and shoots of the strawberry plants and that this reduction was greatest in those plants sprayed with esters of low molecular weight. Further, on a percentage basis, the plants treated with the short chain esters showed a greater reduction in the dry weight of the shoots as compared to the roots of the plants than those plants sprayed with the high molecular weight solutions. It is possible that this differential effect on dry weight of the shoots might have been due to either a physical or chemical difference in the ester. It has been reported by Frear (5) that esters of an aliphatic nature can penetrate the cuticle of plants readily but once inside the leaves, they do not enter the aqueous phase in any appreciable amount. He suggests such forms of 2,4–D to be effective in killing the leaves of plants, but that they are not translocated as well as the salts or esters formed from higher alcohols which are soluble in both water and lipoids.

SUMMARY

Five esters of varying molecular weight including the methyl, ethyl, butyl, butoxyethanol and propylene glycol butyl ether esters of 2,4–D were applied to Blakemore strawberry plants growing in the greenhouse at two different rates.

1. The dry weights of the shoots and roots of the plants treated at the rate of 1 milligram per plant were not significantly different from the unsprayed controls. Further, there were no significant differences between plants receiving different chemicals.

2. All of the esters applied at the rate of 4 milligrams per plant significantly decreased the dry weight of roots and shoots when compared with the controls. Furthermore, this repressive effect on growth had a definite relationship to the molecular weight of the

ester, as the molecular weight increased the dwarfing effect decreased.

3. Malformation of the leaves and petioles of the plants receiving 4 milligrams of the various ester forms was pronounced. Application of all esters produced rather severe injury to the youngest roots. Injury was observed to be greatest in the youngest or tip of the individual root. Secondary roots were killed back more severely than the primaries.

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Chemical Weed Control in Garden Chrysanthemums[1]

R. J. Stadtherr and R. E. Widmer[2]

Each year increasing numbers of garden chrysanthemums *(Chrysanthemum morifolium* Ram.) are grown in the field by commercial nurseries. The cost of labor for weeding and the scarcity of efficient seasonal labor presents a serious problem. This study was undertaken to determine if weeds in chrysanthemum plantings could be safely controlled chemically.

Materials and Methods

Weed control trials were conducted in garden chrysanthemums growing in a silt-loam soil on the St. Paul campus of the Univ. of Minnesota. The area used had been planted to chrysanthemums for over 20 years. It was infested primarily with purslane *(Portulaca oleracea* L.), redroot pigweed (*Amaranthus retroflexus* L.), foxtails (*Setaria* spp.) and crabgrasses (*Digitaria* spp.) plus a small population of black night shade (*Solanum nigrum* L.), lamb's quarter (*Chenopodium album* L.), prostrate pigweed (*Amaranthus graecizans* L.), dandelion (*Taraxacum officinale* Weber), black medic (*Medicago lupulina* L.) and shepherd's purse (*Capsella bursa-pastoris* L.). Post-planting treatments were applied in three successive years, 1955 through 1957. Pre-planting tests were conducted in 1956 and 1957. The most effective materials from each year's trials were compared with new materials in the following year's experiments.

The chemicals were applied to replicated 3 x 8 foot plots, each containing four chrysanthemum plants. Plants which had been grown in 2½ inch containers were planted in the field at a 2 x 3 foot spacing.

On June 6, 1955, four varieties (Chippewa, Minnbronze, Purple Star and Minnesota Selection No. 51–122–7) were planted in blocks in each of three replications. Within each of these variety blocks, the following herbicides (Table 1) were applied on June 14: 1.7 pounds per acre sodium 2,4,5–trichlorophenoxyethyl sulfate (2,4,5–TES), 1.8 and 3.6 pounds of sodium 2,4–dichlorophenoxyethyl sulfate (sesone), 0.4 and 0.8 pound of 3–(*p*–chlorophenyl)–1,1–dimethylurea (monuron), 3.6 pounds N–1–naphthylphthalamic acid (NPA) and mixtures of 2.3 pounds NPA plus 2.3 pounds sesone and 0.4 pound monuron plus 3.6 pounds sesone. Two contact-type herbicides were applied on July 1. These were 80 gallons Stoddard solvent and 7.3 and 10.9 pounds of potassium cyanate (KOCN).

A second application was made on July 20, 1955, using the same chemicals on those plots which had received 2,4,5–TES as well as sesone and NPA alone and in combination at the time of the first application. Isopropyl N–(3–chlorophenyl)carbamate (CIPC) at 4.0

[1]Paper No. 3896, Scientific Journal Series, Minn. Agri. Exp. Sta.

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Table 1. Weed control obtained with post-planting applications of herbicides in garden chrysanthemums, 1955.

Herbicide	Rate lb/A	Date of application		Weeds/6 sq. ft.	
		First study	Second study	July 13	Sept. 1
2,4,5-TES	1.7	June 14	July 20	107.0	69.7
Sesone	1.8	June 14	July 20	83.7	154.7
Sesone	3.6	June 14	July 20	55.7	168.3
Monuron	0.4	June 14	—	68.0	—
Monuron	0.8	June 14	—	38.0	—
NPA	3.6	June 14	July 20	86.7	69.0
NPA + Sesone	2.3 + 2.3	June 14	July 20	55.7	53.7
Monuron + Sesone	0.4 + 3.6	June 14	—	12.7	—
Stoddard Solvent	80 gal.	July 1	—	29.7	—
KOCN	7.3	July 1	—	139.0	—
KOCN	10.9	July 1	—	145.0	—
CIPC	4.0	—	July 20	—	85.7
CIPC	6.0	—	July 20	—	22.0
Check	—	—	—	164.0	228.3
LSD at 5% level				19.5	18.8
LSD at 1% level				26.5	26.1

and 3.8 pounds per acre was applied to those plots which had been treated previously with 7.3 and 10.9 pounds of KOCN, respectively. No second application was made on plots which had been treated with monuron in the first test.

Table 2. Weed control with pre-planting applications of herbicides and plastic mulch in garden chrysanthemums, 1956 and 1957.

Herbicide or treatment	Rate-lb/100 sq. ft.	Weeds/6 sq. ft.	
		1956 trial	1957 trial
DMTT	0.4	—	7.3
DMTT	0.6	8.6	—
DMTT	0.9	—	1.3
SMDC	0.5	—	2.3
SMDC	1.0	11.6	0.0
SMDC	1.5	15.2	—
Black plastic	—	—	6.0
Check	—	45.2	132.3
LSD at 5% level		15.6	24.6
LSD at 1% level		21.9	35.0

In 1956, only one variety, Wanda, was used. Pre-planting treatments of sodium methyldithiocarbamate (SMDC) and 3,5-dimethyltetrahydro-1,3,5,2H thiadiazine-2-thione (DMTT) as shown in Table 2 were applied on June 12 and replicated five times. The indicated rates of SMDC (Vapam) were mixed with 10 gallons of water and this application was followed by an application of 15 gallons of water per 100 square feet. DMTT (Mylone) was mixed with water and added at the rate indicated in 10 gallons of water per 100 square feet, followed by an additional 34 gallons per 100 square feet. The plots were planted on June 27.

The 1956 post-planting treatments were applied on June 29 to plots replicated five times, immediately after the area had been cultivated. Treatments, which are shown in Table 3, included a combination of 4.0 pounds CIPC plus 5.4 pounds trichloroacetic acid (TCA).

Table 3. Weed control obtained with post-planting applications of herbicides in garden chrysanthemums, 1956 and 1957.

Herbicide	Rate lb/A	Weeds/6 sq. ft.	
		1956 trial[a]	1957 trial[b]
Monuron	0.8	6.8	15.0
Sesone	5.4	10.6	—
Monuron + sesone	0.4 + 3.6	10.4	22.0
NPA + sesone	2.3 + 2.3	10.2	—
CIPC	6.0	10.2	—
CIPC	8.0	—	24.8
CIPC + TCA	4.0 + 5.4	9.2	16.3
Simazin	0.5	—	20.3
Simazin	1.0	—	14.8
CDT	1.0	—	112.8
CDT	2.0	—	73.5
EPTC	3.9	—	42.3
DMA	1.5	—	114.3
CDAA	4.0	—	22.0
Check	—	45.2	109.8
LSD 5% level		10.7	19.3
LSD 1% level		14.6	25.9

[a]Herbicide applied June 29; weeds counted Sept. 29.
[b]Herbicide applied June 5; weeds counted July 17.

In 1957, pre-planting treatments, as shown in Table 2, were applied on June 5. In addition to the applications of SMDC and DMTT, a black plastic (1½ mil polyethylene) soil covering was included as a treatment. Plants were placed in the field on June 17. Each treatment was replicated five times.

Post-planting herbicides were applied on June 5, 1957, 1 day after the chrysanthemums were planted. Herbicides not used in previous trials included 2–chloro–4,6–bis(ethylamino)–s–triazine (simazin), 2–chloro–4,6–bis(diethylamino)–s–triazine (CDT), ethyl N,N–di–*n*–propylthiolcarbamate (EPTC), disodium monomethylarsonate (DMA) and 2–chloro–N,N–diallylacetamide (CDAA). Each treatment (Table 3) was replicated four times.

All herbicides were applied at 30 psi using a knapsack sprayer with a flat spray nozzle. Sprays were directed, as much as possible, so as to avoid contacting the chrysanthemums. Rates of application are given on an active ingredient basis. With the exception of Stoddard solvent and the soil sterilants, all herbicides were applied in about 120 gallons of water per acre. When the soil was dry, the area was thoroughly watered 1 day prior to applying the herbicides.

The effectiveness of the chemical treatments was determined by counting the weeds in a 1 by 6 foot area in the center of each plot. Weed counts were made when the weed population in some treatments appeared to give excessive competition to the chrysanthemum plants. With one exception, the counts were made at least 4 weeks after treatment. No herbicidal injury to the chrysanthemum plants was noted except where indicated.

RESULTS

In the first 1955 study weeds were counted on July 13. The weed population in the control plots consisted of about 86 per cent purslane, 10 percent annual grasses, primarily crabgrass and foxtail.

about 3 percent redroot pigweed and the remainder in a wide range of other broadleaf weeds. Since the chrysanthemum varieties did not respond differently to the herbicides, the weed counts obtained in the varietal plots were combined for each of the treatments. The weed counts, as means of the three replications, are given in Table 1 for each of the herbicide treatments.

All treatments except KOCN gave highly significant weed control. It was noted that the KOCN, even though applied in a solution containing a spreader-sticker, did not adhere to the leaves of the purslane plants. This may account for its failure to give measurable weed control. The two most effective herbicides were Stoddard solvent at 80 gallons per acre and a mixture containing 0.4 pound monuron plus 3.6 pounds sesone. Stoddard solvent, however, gave no residual control as indicated by the fact that numerous tiny seedlings were present in the Stoddard solvent treated plots. Since it was evident that these seedlings had emerged just prior to the weed count, they were not included in the count given in Table 1.

The weather was hot and dry on both application dates for the first 1955 study. The mean air temperature for the 6-day period prior to the June 14 application was 56° F and precipitation for the same period totaled 0.24 inch. The mean temperature for the 6-day period following the June 14 application was 70° F and precipitation totaled 0.16 inch. The mean temperature for the 6-day period prior to the July 1 application averaged 69° F and precipitation totaled 0.19 inch. For the 6 days following the July 1 application, the mean temperature was 76° F and precipitation totaled 3.85 inches.

All treatments in the second 1955 study (Table 1) significantly reduced the weed population, but the plots which were treated with CIPC at 8.0 pounds had significantly less weeds, at the 1 percent level, than did all other treatments. There were no significant differences in varietal responses of the chrysanthemums to the herbicides in either 1955 study.

July 20, the application date, was hot and dry. The mean temperature for the 6-day period preceding July 20 was 73° F and precipitation totaled 0.04 inch. The mean temperature for the 6-day period following July 20 was 76° F and precipitation totaled 0.02 inch. Plots were thoroughly watered 2 days after spraying. Weed counts, taken on September 1, are also given in Table 1.

In 1956 all plots which were treated prior to planting were relatively weed free for approximately 4 weeks. The results of the weed counts taken on July 15 are given in Table 2. The reduction in weed populations in all treatments when compared with the control was highly significant.

Air temperature was 96° F at the time the chemicals were applied. The mean temperature for the 6-day period prior to the June 12 application was 75° F and precipitation totaled 0.39 inch. For 6 days following the June 12 application, the mean temperature was 76° F and precipitation totaled 3.82 inches. The soil temperature 6 inches beneath the surface was 86° F.

Results of the 1956 post-planting treatments are shown in Table 3. Reduction of the weed population was highly significant in all treatments.

The weather was warm and partly cloudy. The mean temperature for the 6-day period prior to the June 29 application was 67° F and precipitation totaled 3.28 inches. For the 6-day period following June 29, the mean temperature was 71° F and precipitation totaled 0.29 inch. The results of weed counts taken on September 29 are given in Table 3. All treatments gave highly significant weed control, but did not differ significantly among themselves.

All 1957 pre-planting treatments were highly effective in reducing the weed population, as indicated in Table 2. Most of the weeds in the black plastic treatment were found in openings in the seam which ran lengthwise through the center of the plots. Plants grown in rows mulched with black plastic and in the control plots were about 25 percent smaller on an average than were plants in the DMTT or SMDC treated plots.

The weather at the time of application was sunny and warm and the soil temperature 3 inches below the surface was 72° F. The mean air temperature for the 6-day period prior to the June 5 application was 63° F and precipitation totaled 0.42 inch. For the 6-day period following June 5, the mean temperature was 65° F and precipitation totaled 0.91 inch.

In the 1957 post-planting treatments all herbicides except CDT at the lower rate of application and DMA significantly reduced the weed population. Although CDT at the higher rate of application and EPTC significantly reduced the weed population, excessive numbers were still present in the plots. CIPC plus TCA, simazin at both application rates, monuron, sesone plus monuron and CDAA significantly reduced the weed population at the 5 percent level over EPTC. CIPC appeared to be more effective than EPTC from a practical standpoint, even though the difference between these treatments was not evident statistically.

Plants in the plots treated with simazin showed injury. Plants were smaller and showed marginal leaf yellowing and burning. Symptoms were first observed on July 2. Two out of 16 plants showed injury at the lighter rate of application. Out of a total population of 16 plants, three plants were killed and seven were injured at the heavier rate of application.

DISCUSSION

All pre-planting treatments which were tried during two growing seasons provided satisfactory weed control for approximately 4 to 6 weeks. These were: SMDC applied at the rate of ½, 1 and 1½ pounds per 100 square feet; DMTT applied at the rate of 0.4, 0.6 and 0.9 pound per 100 square feet and a black plastic film soil covering. The sterilants appeared to be more effective in 1957 than in 1956. This might be explained by the fact that run-off water from heavy rains in 1956 flowed across the plots and that weed seeds could have been carried into the treated plots.

Mulching the soil around chrysanthemums with black plastic film provided very good weed control, but the plants were smaller than those in the plots treated with soil sterilants. Since plants in the control plots were also smaller, this reduction in size might be attributed to the presence of harmful soil organisms which could have been at least partially controlled in the plots treated with SMDC and DMTT. No check was made of the microorganisms in the soil. A check for nematodes in the area indicated that significant populations of known injurious types were not present.

Several post-planting applications of herbicides proved highly effective in controlling weeds. Monuron at 0.8 lb/A, monuron at 0.4 lb/A plus sesone at 3.6 lb/A and CIPC at 6.0 lb/A or 3.6 lb/A gave excellent results over the 3-year test period.

A combination of 4.0 pounds of CIPC plus 5.4 pounds of TCA was quite effective during two years' trials. CDAA gave good weed control in one year's tests. Although simazin provided good weed control in a single year's trials, it caused injury to the chrysanthemums at both 0.5 and 1.0 lb/A. A lower rate of application might prove equally effective for weed control with less phytotoxicity to the chrysanthemum plants.

SUMMARY

1. Weed control studies in garden chrysanthemums using both pre- and post-planting treatments were conducted over a 3-year period.
2. The soil sterilants SMDC and DMTT applied as pre-planting treatments provided satisfactory weed control for 4 to 6 weeks.
3. Covering the soil around chrysanthemums with a black plastic film provided very good weed control.
4. The following post-planting treatments gave excellent weed control over the 3-year test period: monuron at 0.8 lb/A, monuron at 0.4 lb/A plus sesone at 3.6 lb/A, and CIPC at 6.0 and 8.0 lb/A.
5. A combination of CIPC at 4.0 lb/A plus TCA at 5.4 lb/A was effective as a post-planting treatment during 2 years' trials.
6. CDAA at 4 pounds per acre gave good weed control in one year's test as a post-planting treatment.

The Relationship of Soil Adsorption of EPTC to Oats Injury in Various Soil Types[1]

FLOYD M. ASHTON and THOMAS J. SHEETS[2]

ETHYL N,N-di-*n*-propylthiolcarbamate (EPTC)[3] has shown promise as a pre-emergence herbicide in both greenhouse and field studies. Antognini[4] reported that EPTC was quite volatile. In volatility studies in this laboratory the loss of unformulated technical EPTC from a free liquid surface was 57 micrograms/sq cm/hr at 30° C. It was difficult to understand how a compound as volatile as EPTC could be an effective pre-emergence herbicide. Preliminary tests, utilizing radioactive EPTC[3], demonstrated that it was less volatile from soil surfaces than from stainless steel or leaf surfaces, indicating that a soil adsorption phenomenon might be involved. Greenhouse studies showed that at a given concentration of EPTC in the soil the phytotoxicity to oats (*Avena sativa* L.) was not the same in the various soil types studied. The purpose of this study was to investigate the relationship between soil adsorption of EPTC and oats injury in several soil types.

MATERIALS AND METHODS

The toxicity of EPTC to oats was investigated in five soil types under greenhouse conditions. The procedure has been described in detail (2). Portions of oven-dry soil weighting 500 grams each were placed in No. 2 metal cans. The formulation of EPTC, containing 6 pounds of active chemical per gallon, was added to the soils as a water emulsion at 0.0, 0.31, 0.62, 1.25, 2.5, 5.0, 10, 20, 40, 80, and 160 ppm or milligrams per 1000 grams of soil. Thirteen oat seeds were planted per can. Fresh weights of the plant parts above the soil surface were taken after 30 days. The concentration which reduced the fresh weight of oats 50 per cent (ED_{50}) was determined for each soil. These values were obtained by plotting the fresh weights, as percents of the control, against the logarithm to the base 10 of the concentration and constructng a free-hand curve to fit the points. The point on the concentration axis which corresponded with the point of intersection of the curve and to 50 percent yield level was the ED_{50} as a logarithm. The antilogarithms of the 50 percent points gave the ED_{50} in ppm. All determinations were replicated three times.

The adsorption of EPTC vapor by the five soil types was determined by placing 2 grams of air dried soil (20–40 mesh) in a cupped

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[1]Cooperative investigations of the Crops Research Division, ARS, USDA and the California Agric. Experiment Station.

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[3]Experimental samples supplied by the Stauffer Chemical Company, Mountain View, California.

[4]Antognini, J., Mountain View, California, personal communication.

Table 1. The effect of soil type on the toxicity of EPTC to oats and on the soil adsorption of EPTC vapor.

Soil type	Organic matter %	Clay %	Oats injury ED_{50}[a,b]	Soil adsorption (counts/minute)[b]	
				Soil at field capacity	Soil air dry
Egbert series	4.8	79.5	1.55 a	44.5 a	225 a
Yolo silty clay	2.4	45.0	1.20 b	31.5 b	169 b
Yolo clay loam	2.4	38.7	0.88 c	32.8 b	157 bc
Yolo sandy clay loam	1.4	22.5	0.44 d	22.0 c	158 bc
Hesperia sandy loam	0.3	16.0	0.24 e	17.5 c	127 c

[a]The ED_{50} is the concentration in ppm which reduced the fresh weight of oats 50 percent.
[b]Means with the same letters do not differ significantly at the 5% level of probability.

planchet 1 inch in diameter. The soil in one-half of the planchets was brought to approximately field capacity by slowly adding water, one drop at a time, to the soil at one edge until all the soil was moist. The planchets were placed in an air tight container. One-half ml of EPTC containing 30 microcurries of S^{35} was added to the container and the container sealed. The planchets were removed from the container after a 12-hour exposure. The moistened soils were dried at room temperature and all planchets counted by means of a thin window Geiger tube and suitable scaler. All counts reported are net counts per minute. All determinations were replicated four times.

RESULTS AND DISCUSSION

The toxicity of EPTC to oats in the five soil types is shown in Table 1. All ED_{50} values are significantly different from one another as determined by Duncan's range test (1). There was a direct relationship between the ED_{50} values and the percent clay and the percent organic matter in the various soils. An examination of the two extreme soil types shows that there was a 6.5 fold difference in the concentration of EPTC required to reduce the fresh weight of oats 50 percent. It is, therefore, apparent that soil type is a factor in determining the amount of EPTC required to obtained equivalent herbicidal effectiveness.

The adsorption of EPTC vapor by the five soil types is also shown in Table 1. The data are presented as the mean net counts per minute for the field capacity and air dry soils. The adsorption of EPTC was greatest on the Egbert soil in both wet and dry condition. When the soils were at field capacity the amount of EPTC adsorbed was least with Hesperia sandy loam and Yolo sandy clay loam. Adsorption by Yolo silty clay and Yolo clay loam was intermediate between the extremes. The trend was similar but not identical for air dry soil.

The relationship between oats injury and soil adsorption of EPTC in the various soil types is apparent from the data in Table 1. EPTC was adsorbed the least on those soils in which it was the most phytotoxic. Apparently EPTC is adsorbed by the surfaces of the soil particles preventing its loss as a vapor; however, a portion must be held so tenaciously that it is physiologically inactive. The amount

rendered inactive would vary with the adsorptive capacity of the soil.

EPTC was adsorbed to a much greater extent by air dry soils than those soils which had a soil moisture content near field capacity (Table 1). This is probably because in soil at field capacity each soil particle is surrounded by a thin film of water and the slightly water soluble EPTC does not come into as intimate contact with the individual soil particles as in the air dry soils.

The variability in results which have been obtained with EPTC in field tests is undoubtedly due, in part at least, to different soil types and dfferent soil moistures. The importance of these two critical factors have been demonstrated by the experimental data presented.

SUMMARY

The effect of soil type on the phytotoxicity and the adsorption of EPTC was investigated. There was an inverse relationship between oats injury and soil adsorption of EPTC in the various soil types. Apparently the loss of the volatile EPTC is prevented by its adsorption by the soil particles, however, a portion must be held so tenaciously that it is physiologically inactive. EPTC was adsorbed to a much greater extent by air dry soil than by soil with a soil moisture content near field capacity.

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A Logarithmic-Concentration Sprayer for Small Plot Use

J. K. Leasure[1]

In 1955, three British workers (2) described a variable dosage sprayer which was designed for large field plots. The original description did not attract much attention in the United States when it was first published, but the principles described therein are receiving more attention at the present time, both in this country and abroad (1).

The operational theory of the logarithmic-concentration sprayer is quite simple. The pressure in the system forces liquid from the nozzle. The first liquid to flow is the full strength material from the concentrate tank. It is immediately replaced by material from the diluter tank, and the concentration of material in the concentrate tank decreases. The concentration of material at the nozzle thus decreases much in the manner of a half-life curve for radioisotopes.

Such a sprayer to be safely and easily operated should have other accessory features, some of which are essential to its proper functioning. The feature most important to proper functioning of the sprayer is an agitator to insure that the concentrate and the diluent in the concentrate tank are thoroughly mixed at all times. Other features which are desirable are listed below:

1. Pressure gauges on the diluent tank and at the nozzle.
2. Quick opening filling valves with integral filling funnels on both tanks.
3. Drain and vent valves on each tank.
4. Proper safety valves and blow-out plugs.

The concentration of chemical at the spray nozzle at any given time is a function of several variables: the discharge rate, the volume of the concentrate tank, the starting concentration, and time since the start of the run.

The nozzle discharge rate is itself a function of both orifice size and operating pressure. Changing the discharge rate will change the rate at which the diluent will enter the concentrate tank, which will change the time-rate curve.

If the concentrate tank has a large volume relative to the discharge rate, dilution will be slow, and the concentration curve will be quite flat. If this volume-discharge ratio is smaller, the curve will be steeper. In designing such a sprayer, it is very important to pick a tank size which gives the desired concentration gradient over the distance to be covered, using standard nozzle tips and a reasonable pressure. If the sprayer is designed with these factors in mind, the use of different nozzle-tips or machine speeds will result in enough changes in the concentration delivery curve to be satisfactory for most field requirements.

Similarly, the speed of the sprayer over the ground will affect the concentration at any given distance along the row, although it

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will not affect the time-concentration relationship. A change in speed will, of course, change the volume of spray applied per acre.

It can be seen that considerable latitude exists in rates of chemical and volume of spray which can be applied per unit area by changing the starting concentration, the nozzle-tip, or the speed.

The rate-time relationship for a particular system can be determined mathematically by the following formula:

$$\text{Log}_e \frac{C_o}{C_t} = \frac{(kR - m)t}{V}$$

Where C_o = The original concentration
C_t = Concentration at time t
R = Rate of flow
t = Time
V = Volume of concentrate tank
k, m = Constants for any given system

In this equation, both concentrations must be in the same units, and the rate, time and volume units must correspond.

For example, if R is expressed in ml/sec, t must be expressed in seconds and V in milliliters. The constants seem to be related to the volume and diameter of the connecting pipes, but in general k is close to unity and m is quite small and they have no large effect in the equation.

These constants were determined as follows:

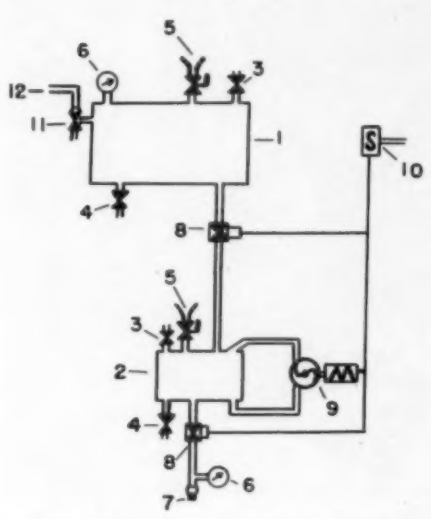
1. The actual time-discharge pattern was developed by collecting samples from the nozzle at 5-second intervals during a run and analyzing them.
2. The best fitting curve was determined mathematically, using the basic formula given above.
3. Analysis of data from subsequent runs with different starting concentrations and using nozzles with different discharge rates indicated that the same constants were suitable for use under these varying conditions.

During the winter of 1955, workers engaged in Agricultural Research at the Dow Chemical Company met to discuss the application of these principles to some of the agricultural research projects then underway. The group then proceeded to design an extremely versatile small plot sprayer which was built in time to be field-tested in 1956.

It was decided that a speed of 1 mph would be satisfactory, and that the machine should dilute through a concentration range of approximately 7 to 1 over a 100 foot row, when used with a nozzle delivering 0.4 gpm. This range could be varied by using a smaller or larger nozzle.

The sprayer was therefore constructed using a concentrate tank holding approximately 900 ml, a diluent tank holding about 3 gallons, and using a standard TeeJet nozzle with interchangeable tips. The system was pressurized by nitrogen from a high pressure cylinder (2000 psi) through a suitable reducer.

In order to keep the contents of the concentrate tank adequately mixed, a small electrically driven centrifugal pump was mounted to recirculate the contents of the concentrate tank. This pump takes a suction from the bottom of the tank and discharges at an angle in the top, setting up a whirling motion in the cylindrical tank. The pump capacity is sufficient to recirculate the tank contents each two-fifths of a second and this is adequate to suspend wettable powder formulations at rates up to 200 pounds of dry formulation in 40 gallons of water.



1 DILUENT TANK
2 CONCENTRATE TANK
3 VENT VALVE
4 DRAIN VALVE
5 QUICK-OPENING VALVE WITH FILLING FUNNEL
6 PRESSURE GAUGE
7 NOZZLE
8 SOLENOID VALVE
9 CIRCULATING PUMP AND MOTOR
10 110 VOLT SUPPLY LINE SWITCH
11 SAFETY VALVE
12 PRESSURE IN

Figure 1. A line diagram of the principle features of the logarithmic-concentration sprayer.

Solenoid operated valves were installed between the diluent tank and the concentrate tank and between the concentrate and the nozzle. These valves are wired into the starting switch for the recirculating motor so that a single switch activates the system. Figure 1 is a line diagram showing the components of the spraying system used in this machine.

The sprayer was built on a magnesium frame and mounted on bicycle wheels. It is self propelled by an electric motor and sprocket chain drive coupled with variable diameter V-pulleys for speed control from 1 to 3.5 mph. A separate switch operates the power drive, and the whole unit is powered by a portable gasoline driven generator through a 125 foot extension cord. With this equipment thirty 100 foot rows (40 inch centers) can easily be sprayed without moving the generator. Figure 2 is a photograph of the machine as described.

Although the theoretical curves for this machine were calculated, the machine was actually calibrated by means of refractive index measurements of calcium chloride solutions. The concentrate tank

Figure 2. The logarithmic-concentration sprayer built by the Agricultural Chemical Research group of The Dow Chemical Company. Numbers correspond to the parts identification used in Figure 1. The recirculating pump and motor are not visible in this view, but are located immediately behind the concentrate tank.

was filled with calcium chloride solution, the diluent tank with water, and spray samples were collected at 5-second intervals. The results of this calibration fit the theoretical curves within the limits of sampling error and are shown in Figure 3.

Plants respond in a readily measurable manner to concentration variations of this type, provided the initial concentration is such that some plant response is assured. This is illustrated by data obtained by spraying corn plant 4 to 6 inches tall with solutions of 2,2–dichloropropionic acid (dalapon).

The plants, growing in pots, were set at 1-foot intervals in 100-foot rows and sprayed. One row was sprayed starting with 10,000 ppm dalapon, and another starting with 4,000 ppm dalapon. This procedure was repeated, using 2 different wetting agents in the dalapon formulation.

After 3 weeks the plants were cut, and green weights determined for groups of five consecutive plants. The data are presented in

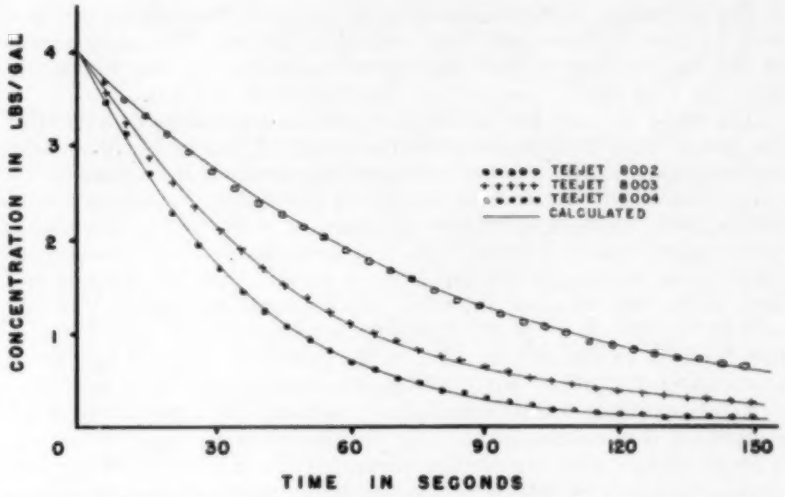


Figure 3. The results of calibration trials with the logarithmic-concentration sprayer, in which $CaCl_2$ solution was collected for analysis at 5-second intervals during runs with three different sizes of nozzle tips.

Figure 4, and show the biological response which can be obtained when using the logarithmic-concentration sprayer. A good indication of the reproducibility of such responses can be obtained by

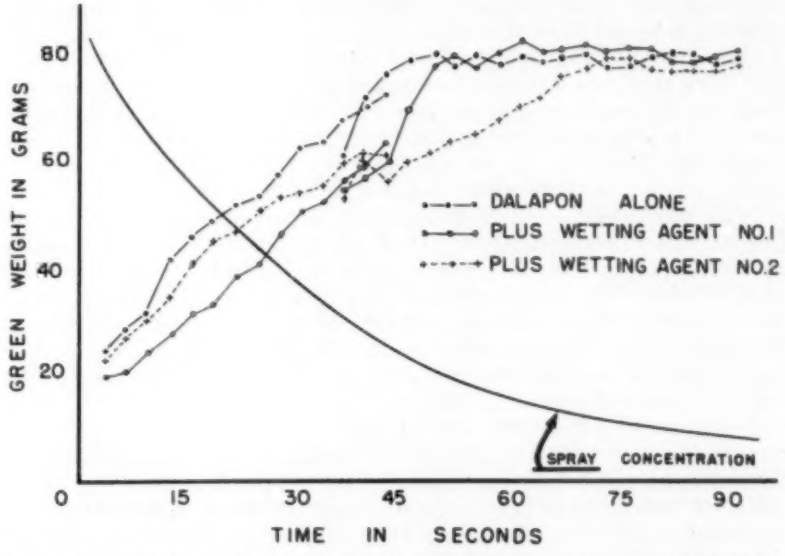


Figure 4. The green weight in grams of groups of five consecutive corn plants from rows sprayed with the logarithmic-concentration using dalapon alone and dalapon with two different wetting agents.

noting the overlapping results from the end of the 10,000 ppm run and the start of the 4,000 ppm run in each case. The effectiveness of the wetting agents used in the formulation can also be clearly seen.

The most obvious use for such a sprayer is the determination of the proper rate of application of chemicals. This can be illustrated by describing a field test with several experimental insecticides.

One hundred foot rows of cucumbers and beans were planted 6 inches apart, with 3 feet between pairs of rows. When the plants were approximately 4 inches tall, they were sprayed with the insecticides, using a rate decreasing from 3 pounds per 100 gallons per acre at the beginning of the rows to 0.3 pound per 100 gallons per acre at the end of the rows. Stakes were placed in the rows to mark the position of the nozzle after each 10 second interval to aid in calculating the rate at any given point along the row.

Readings made 5 days later clearly showed the rate range which controlled the insects and the rate below which no injury occurred. This procedure very clearly demonstrated the safe limits of application—the range in rate which controlled insects without injury to the plants. To evaluate rates with standard small plots, 12 different rates per compound would have yielded much less information, and would have required more space and more time to apply.

There are a number of other problems which can be studied very effectively by the use of a logarithmic-concentration sprayer. Some of them are illustrated in order of increasing complexity.

Two similar materials can be compared very easily by placing material A at a given concentration in the concentrate tank, and placing material B at the same concentration in the diluent tank. This will apply the two materials together at a constant rate, but will vary the proportions as material B flows into the concentrate tank. At the beginning of the run, the spray material will be exclusively A, while at the end of the run it will consist largely of material B. By observing the plants along the row the effect of the two chemicals can be determined relative to each other.

A simple modification of this technique permits holding one spray ingredient constant while varying another. Such a system would allow the evaluation of a wetting agent over a wide range of concentration with a fixed concentration of chemical. For such a test, both tanks would contain the material to be held constant, while only the concentrate tank would contain the materal to be varied. For these types of applications, the two materials must be compatible, but can be of different formulations.

For those who specialize in the complex, it should be emphasized that we have not yet utilized all the capabilities of this remarkably versatile machine. The concentrate tank could be loaded with two different materials at different rates, and the diluent tank with two more materials. The machine would then apply them precisely, all 4 at varying rates. The principle argument against such a procedure is that it is difficult to evaluate the individual variables in such a treatment combination.

In summary, it can be said that this machine is extremely useful in several field situations:

1. Where rates are to be determined.
2. Where the effects of additives are to be studied.
3. Where combinations are to be studied.
4. Where similar materials are to be compared.

The logarithmic concentration sprayer can often be used in such situations with a significant saving in space, time, and labor. In addition, it often provides striking demonstrations of the results in the field.

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A Visual Aid for Illustrating Herbicidal Chemical Structures and Teaching Chemical Nomenclature

W. A. Gentner, W. C. Shaw, and L. L. Jansen[1]

The chemical nomenclature used in connection with herbicidal compounds is frequently difficult for individuals who have little training in chemistry. A large molecular model has been constructed as a visual aid to facilitate audience comprehension of chemical nomenclature and to demonstrate relationships between chemical structure and herbicidal activity. The present model is designed to illustrate four of the major classes of herbicides, but it can be further modified in design to illustrate other herbicide classes.

Construction

A large size molecular model, as illustrated in Figure 1, can be conveniently cut from a 21 x 36 inch piece of 4-ply illustration board. The basic board used in the present model is 14½ x 21½ inches containing a 6-membered unsaturated ring in a centered position. Small square windows (W) are cut opposite the five free bonds drawn at the bottom and side positions of the ring. A large, centered horizontal window is cut out above the top or 1-position. Similar modified window cut-outs are made in two rectangular strips, A and B in Figure 1 and 1A. These pieces are mounted on the back of the basic board so as to make the openings coincide. (Note: Window piece B may be made of thinner material than other parts if desired.)

A linkage bond for the 1-position of the ring is drawn on the stationary projecting block (P in Figure 1) in the window area of piece B. An oxy-linkage (–0–) is drawn on the upper part of an inverted T-slide (0 in Figure 1). This slide is operated up and down in a space provided by removal of a section of the lower part of the frame of window piece A. When in the "up" position the oxy-slide completely covers the projecting block of window piece B. In the "down" position the top of the oxy-slide is flush with the window framing and the bottom rests against a small cardboard stop (not illustrated) which is glued to the back of the basic board. A variety of alkyl moieties and a number of terminal functional groups can be attached at the 1-position of the ring by appropriate manipulation of an assortment of slides (e.g. S1, S2, and S3 in Figure 1). The slides are operated horizontally in front and back of the windowed construction described above. Each slide slips between two slide tracks (T in Figure 1) made of illustration board and glued to the basic structure. Slide guides (G in Figure 1) cut of wider strips of illustration board are glued to the slide tracks and function in keeping the slides properly positioned between the tracks. When a slide bearing an alkyl chain (S1) is moved along the track behind the

[1]Plant Physiologists, Crops Research Division, Agricultural Research Service, U. S. Department of Agriculture, Beltsville, Maryland.

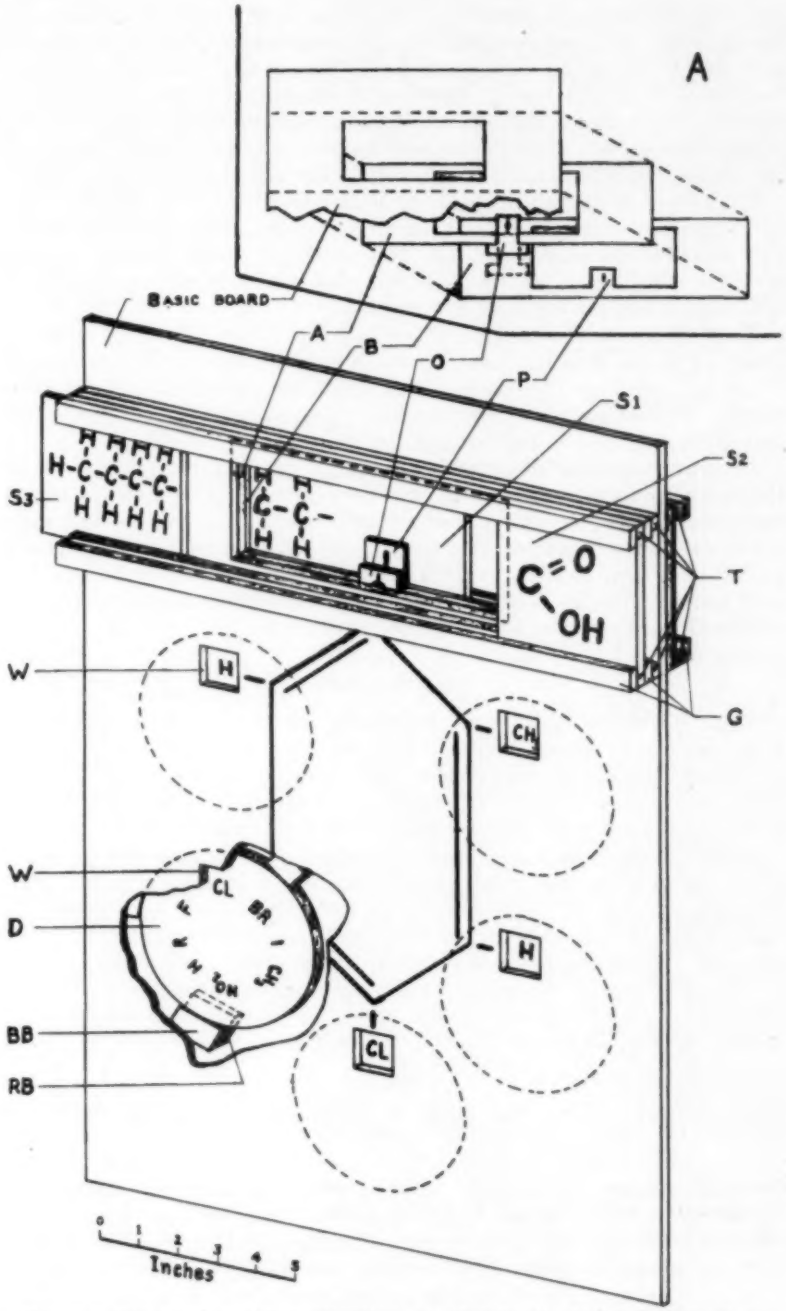

Figure 1. Details of model construction. (A) Details of window construction.

window, the projecting bond (or oxy-slide) in the window substitutes for the lower H-atom attached to each successive carbon of the chain as it moves across the windowed area. Hence, when viewed straight-on, the chain appears to be attached to the ring at the carbon immediately above these linkage groups. Auxiliary slides (S2 and S3) which operate in either of the two front tracks permit extension of the chain and attachment of terminal functional groups as desired.

Variations in groups at all other positions of the ring are achieved by rotation of printed discs (D in Figure 1) mounted in back of the five small windowed openings described previously. The various symbols are printed on the discs in such a way that only one symbol will appear in the window at a time.

Each disc is positioned by three bearing blocks (BB in Figure 1) glued to the back of the basic board. Retaining blocks (RB in Figure 1), which over-lap the back of the discs, are glued to the bearing blocks. To facilitate rotation, a small wooden drawer pull (not illustrated) is attached at the back-center position of each disc.

Insurance against binding of moving parts is provided by use of paper spacers cut to size and glued on at time of assembly. Placement of spacers has been found advantageous (a) between each slide track and its associated slide guide, (b) between window pieces A and B, adjacent to the oxy-slide, and (c) between the disc retaining and bearing blocks. To facilitate operation of the various parts of the model all moving surfaces are paraffined.

PERFORMANCE

A great variety of molecular configurations can be demonstrated with this model depending to a degree on the needs of the individual. It may readily be modified to show compounds belonging to the following chemical families: (1) phenoxy-aliphatic acids and derivatives, (2) phenyl-type compounds, (3) benzoic acids, and (4) phenols.

Phenoxy-aliphatic compounds are formed by moving the oxy-slide (0 in Figure 1) to the "up" position so that it is superimposed upon the linkage bond (P in Figure 1). A basic carbon chain is shown on Slide 1 (S1 in Figure 1) in the rear track and the terminal functional group of the carbon chain is shown on Slide 2 (S2 in Figure 1) carried in one of the front tracks. A variety of aliphatic moieties are formed as follows: The 2-carbon moiety is formed by centering the terminal methyl group (CH_3) on Slide 1 (S1 in Figure 1) over the oxy-slide.

The oxy-slide covers the lower H of the methyl group (H-C...)

forming the desired linkage between the ring and side chain. The terminal functional group is moved in the front track so that it covers the remainder of the carbon chain on Slide 1 (Figure 2A). Longer carbon chains are formed by exposing more of the carbons on Slide 1 and by the use of supplemental carbon chains on the additional front slide track. The carbon chain shown on Slide 1 may be extended

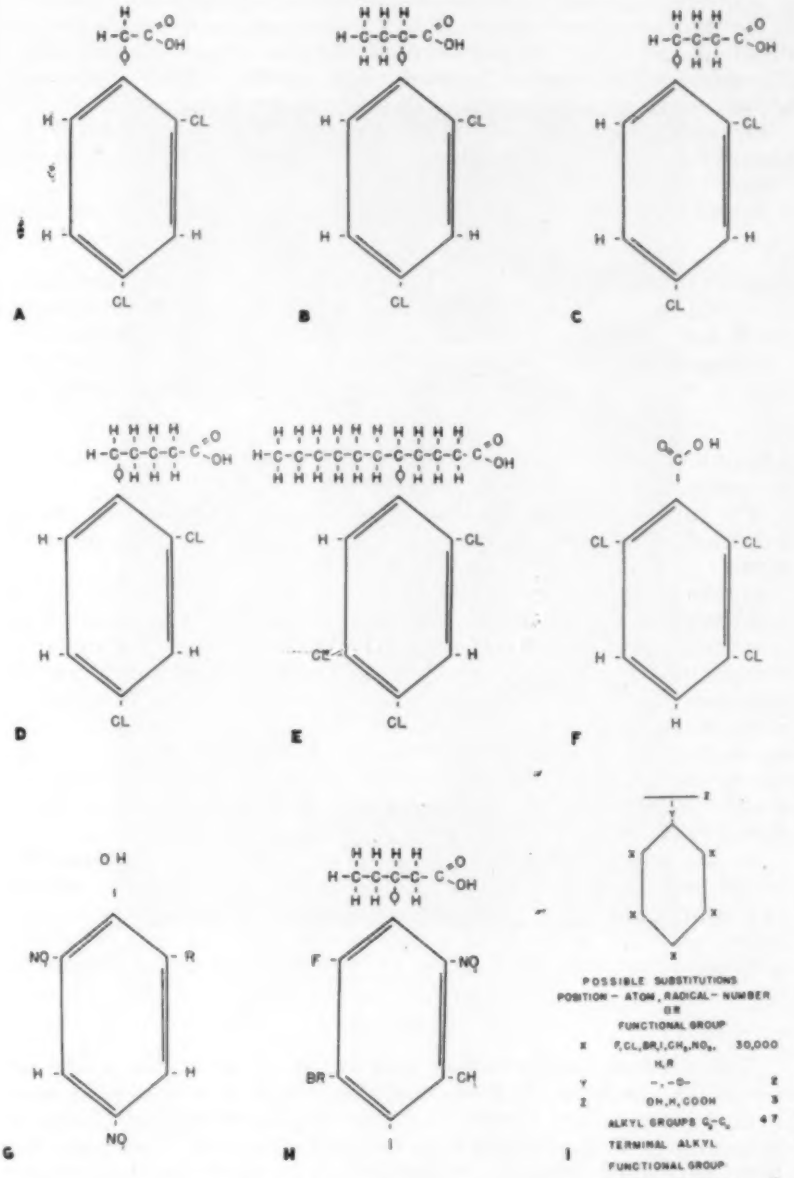

Figure 2. Versatility of the molecular model.

either to the right or left of the point of ring attachment. The positions at which the ring may be substituted in the carbon chain are restricted to the number of carbons on Slide 1 which may be demonstrated to the right and left of the 1-position of the ring (Figure 2B, 2C, 2D). The primary limitation on the total length of carbon chain which may be demonstrated is the length of the slide tracks (Figure 2E).

Phenyl-aliphatic compounds are formed in the same manner as phenoxy-aliphatic type compounds except that the oxy-slide is in the "down" position.

Benzoic acids are formed by removing Slide 1 and reversing it to show a carboxyl group ($\overset{O\ OH}{\diagdown\!\!\diagup C}$) printed on the back (Slide 2 and Slide 3 are removed). The oxy-slide is placed in the "down" position leaving the linkage bond for the 1-position of the ring showing (Figure 2F).

Compounds which are phenolic in structure are formed by reversing Slide 2, which is painted white but not lettered. Slide 2 is positioned in a front slide track so as to cover the ($\overset{O}{\diagdown\!\!\diagup C}$) of the carboxyl group used to demonstrate benzoic acids (Figure 2G).

The number of substitutions which may be demonstrated at the 2-through 6-positions of the ring is determined by the number of atoms or radicals printed on each disc (Figure 2H).

Figure 2I illustrates the versatility of the present model which was designed for the specific purpose of demonstrating certain benzoic acids, phenolic compounds, and phenyl and phenoxy-aliphatic compounds. The number of molecular configurations which may be demonstrated with it is estimated to be over nine million. Additional versatility could easily be obtained through the construction of a wider variety of slides. A large variety of atoms or radicals may be shown on the discs, and several slides carrying terminal functional groups (S2 in Figure 1) may be printed on both sides to give additional flexibility.

In addition to using this molecular model as a teaching and lecturing aid, it has been very useful in making photographic records of research results. The desired chemical configuration may be photographed with plants treated with the chemical or may be photographed separately and inserted or overlaid in printing (Figure 3).

SUMMARY

The construction, function, and use of a molecular model on which four herbicidally important chemical groups may be demonstrated are described herein. Over nine million molecular configurations may be demonstrated with the present model. The model has been successfully used as a visual aid (1) to teach chemical nomenclature, (2) to facilitate audience comprehension of chemical nomenclature, (3) to demonstrate relationships between chemical structure and herbicidal activity, and (4) to make photographic records of research results.

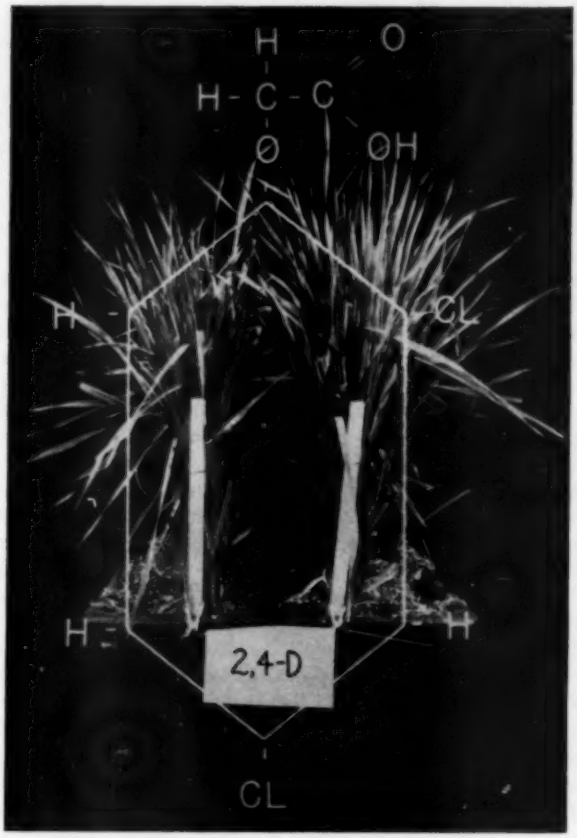

Figure 3. Photographic record of the effect of 2,4–D applied as a post-emergence spray at the rate of ½ lb/A on oats underseeded to several small seeded legumes and broadleaved weeds.

Keeping Extension Agents and Dealers Informed on Weed Control

PAUL W. SANTELMANN and ANDREW A. DUNCAN[1]

THE high cost and scarcity of farm labor and the realization that the control of weeds with chemicals is possible and economical has resulted in greater demand for up-to-date information from all those concerned with weed control. For those charged with the responsibility of research in weed control chemicals and techniques, the additional duties of extension teaching and "trouble shooting" can be burdensome if not properly handled.

Certainly the use of modern herbicides by farmers requires a knowledge of certain detailed information. The best way to convey detailed information is by personal contact. Unfortunately, one or two men working from the State Extension Service office can provide this personal consultation to only a small percentage of the people that require it. Probably the three groups of people who are most frequently asked about controlling a given weed are the county extension personnel, chemical dealers, and friends and neighbors. Unfortunately, extension specialists do not have the opportunity to work with all of the third group that will be giving advice, but certainly they can make an attempt to get information to extension agents and to those selling pesticides.

In Maryland there are at least 18 extension publications dealing with the various phases of chemical and cultural weed control practices. These are widely distributed and useful, but often are quite inflexible once they are printed. Also, publications such as these cannot answer all the specific questions that will arise about the use of a certain herbicide. Usually when these questions come up the farmer asks his local people and is not able to get a completely satisfactory answer. Frequently, the question ends up in the extension specialist's office, but by this time it is often too late to give the information when needed. In practice most of the recommendations are made to farmers by county agents or by chemical dealers and field men, and not directly by extension specialists. These people carry out the extension specialist's ideas and/or statements. It is, therefore, important that the specialists maintain close contact with these groups of people.

The retail chemical dealer is selling products and service. Often, his knowledge is limited to only those chemicals which he is selling. In Maryland we find that farmers expect their chemical dealers to provide field service or "trouble shooting". Thus, dealers and field men are, in effect, farmer advisors and need more information about all herbicides. If they are acting as extension workers, then it is certainly part of the extension specialist's duty to try to help them so

[1]Extension Weed Specialist, Agronomy Department, and formerly Extension Vegetable Specialist, Horticulture Department, resp., University of Maryland, College Park, now Extension Specialist in Canning Crops, Horticulture Department, Oregon State College, Corvallis.

that they can do a better job both of advising the farmers and keeping themselves in business. Where the extension specialist may reach the "innovator" or the "early majority" group, the dealers very frequently are in close contact with the "vast majority" group.

County agents have a large amount of office work that must be done and also, they must know something about a large number of different things. They are very limited in the amount of time they can spend studying or working with one particular phase of their work. Sometimes they are not enthusiastic about chemical weed control as it is another new idea or new practice that must be added to all of the older ones they are already working with. The majority of the county agents in Maryland are schooled in something other than weed control work, and very frequently in something other than plant science. On the other hand, the county agent is asked many questions about weed control and wants to be able to supply satisfactory answers.

Thus, both groups (retail chemical dealers and county agents) need recent information on chemicals to back up the statements and suggestions that they make to farmers. Also, they need to keep up-to-date on weed control problems as they arise, and on suggested solutions. With this in mind the authors have set up a program to work as closely as possible with these two groups of people in order to keep them informed on the varied changes that are occurring in the weed control field. It is felt that this program has helped in getting information from discovery to adoption in a relatively short time and has provided a large group of people with sufficient information to handle some "trouble shooting." These procedures are not for direct contact with the farmer, but have been set up for the county extension personnel and herbicide dealers and field men.

Some of the publications involved are directed at these groups of people and are not particularly intended to go to farmers. Certainly the use of mass media, farm demonstrations, and publications are an important part of an extension specialist's program, but the methods described here are primarily for agents and dealers.

The program followed is composed of five parts:

1. Regional agricultural pesticides conferences are held annually at three locations in the State of Maryland. County extension personnel, chemical dealers and field men, and University extension specialists meet at these conferences and discuss new chemicals and their uses. Extension specialists put together a handbook containing new extension publications dealing with pesticides, and also special publications or tip sheets are made up particularly for this conference. At these meetings new chemicals are discussed in detail. Also, new methods of using the old chemicals and new developments in the handling of various weed control problems are discussed. The dealers and extension personnel are urged to ask questions and to meet the various people whom they do not know. Often, spirited discussions ensue with regard to the results that farmers or experiment station personnel have had from the use of various chemicals. Both chemical dealers and extension per-

sonnel have reported that this has provided them with an excellent opportunity to meet for the first time and to get together and discuss mutual problems.

2. For the past 2 years 2-day regional extension weed schools have been held for county agents. At these schools many subjects pertaining to weeds and their control have been discussed. Some typical subjects have been weed identification, technical chemical information, weed control equipment, and cultural weed control practices. These have had very good attendance from the agents within the region where they were held. Generally two or three speakers from the University have been on the program discussing their particular specialties in the weed control field.

3. The extension editor at the University each month sends out to the extension personnel a publication known as the "Farm Job List." The authors use this to remind the county extension personnel of the weed control spraying jobs that will be coming up during the following month. This provides an excellent opportunity for up-to-the-minute reminders such as "now is the time to spray chickweed in alfalfa."

4. An annual publication for agents and dealers lists the chemicals commercially available for weed control purposes in Maryland. In this publication at present is a list of some 28 different herbicides that are available from dealers in Maryland together with references to extension publications discussing each herbicide, how it acts, a very brief listing of major uses, manufacturers of the chemical and the various trade names under which it is sold. At the end of the publication is a cross reference by trade names. This publication is put together so that if a dealer or an agent receives a question about a particular chemical with which he is not familiar, he can look to this mimeograph and find out something about the chemical whether the question is by trade name or by chemical name.

5. For over 2 years the authors have edited an informally written single sheet publication that is distributed to all extension personnel and chemical company dealers that desire it. It is written so that non-technical people with limited chemical knowledge can understand the information about various chemicals. This publication has a distinctive masthead with the title "Maryland Weed Notes" in green so that it is easily recognized. It is usually restricted to a single sheet of paper so that it cannot become too long. There is no regular publication schedule, but there are about 6 issues a year. Some of the paragraph headings used at various times in this publication are:

a. *"Now is the time."* This gives details on the use and precautions of particular chemicals or weeds that should be treated at the time of publication.

b. *New weed control publications* that have been published since the last issue of "Weed Notes."

c. *Discussion of recent weed problems* that have come up for "trouble shooting" to answer questions that have arisen very frequently.

d. *Announcements,* such as the announcement of the time and location of meetings of the Agricultural Pesticides Conferences.

e. *New chemicals.* Some of the advantages and disadvantages of new chemicals are discussed as they come on the market. Also included is a discussion of their place in the Maryland weed control program.

f. *Weed identification,* frequently a drawing and description of an individual weed is included.

g. *A brief outline of demonstration* or research results on a given problem and perhaps an announcement of the location of some of the demonstrations around the State.

The benefits from this intensive and varied teaching effort have accrued to all those associated with it. While the agents and dealers take information to the ultimate users and handle much more of the trouble shooting, on the other hand they also evaluate results and bring new problems and ideas to those charged with the responsibility of problem solving. Both extension agents and dealers have been enthusiastic in their response to this program. Dealers, in particular, have frequently commented on the helpfulness of the Pesticide Conferences and of "Weed Notes." Dealers and agents often suggest items to be included in "Weed Notes," and say that they have found it to be very helpful in timing their recommendations. The publication is now distributed to over 350 extension agents and chemical dealers throughout Maryland's 23 counties. Certainly the authors have also benefitted tremendously from the closer contact with the people handling herbicides in Maryland.

Regulating the Use of 2,4–D in the Southern States

ERNEST A. EPPS, JR.[1]

THE value of 2,4–dichlorophenoxyacetic acid (2,4–D) for control of broadleaved weeds is well known. It is equally well known that these chemicals can cause serious damage to certain crops. After 10 years of general use in agriculture it is well to review the extent to which 2,4–D has been a source of trouble and to examine regulatory policy with regard to 2,4–D.

As cotton has been the principal crop affected, this discussion is limited to the cotton producing states in the south. Tennessee, Alabama, Georgia, Florida, and South Carolina have no laws regulating the use of 2,4–D. Reports from these states indicate that complaints of 2,4–D damage are few in number and generally not of great economic consequence. Only in those states where rice is produced in the same areas as cotton has the problem become so severe as to invoke legislative action. Louisiana, Mississippi, Arkansas and Texas have specific regulation laws. 2,4–D is included under the general pesticide applicators law in Oklahoma.

In spite of wide publicity on possible harmful effects of 2,4–D, it is difficult for the average person to appreciate the potency of this chemical. As little as 0.01 pound per acre of 2,4–D will cause marked physiological changes in cotton and will reduce yield. Greater amounts cause corresponding reductions in yield. This means that even slight drift of 2,4–D spray may cause trouble. Actual killing of cotton on 2,4–D drift has not been observed. Where the affected crop has been properly cultivated and an insect control program followed there has been recovery and some production of cotton. This has led some to minimize the danger to cotton. Various investigations have shown that if enough 2,4–D to cause pronounced formative effects was present, loss in yield may be expected. Where large acreages are involved the amount of damage can easily reach considerable proportions. Operations of the U. S. Army Corps of Engineers in the Monganza Spillway in Louisiana in 1953 gave rise to more than 2000 damage claims. The amount paid in settlement by the Army has not been divulged but contacts with farmers in the area indicate that a very large sum was involved. In most cases the amount paid in settlement of claims is not readily obtainable. However, some information is available. Last year in Mississippi, settlement of claims in amounts of $3500 to $8700 were made. One case in Louisiana was settled for $7000. It is plain that improper use of 2,4–D can have serious consequences.

One of the most troublesome aspects of the problem is determining the source of the drift responsible for the damage. Where 2,4–D is being applied by a number of persons in the same area at the same time as is the case in Southwestern Louisiana it is not easy to determine who is at fault when damage occurs. Thus some farmers are

[1]Chief Chemist, Louisiana Department of Agriculture and Immigration, Baton Rouge, Louisiana.

not able to recover their losses. Most claims have been associated with aerial applications. Some result from ground (includes boats) operations. Much less frequent have been damages caused by contamination of other pesticides or application equipment. Practically all damage has been attributed to 2,4–D. 2,4,5–Trichlorophenoxy acetic acid (2,4,5–T) and 2,4,5–trichloropropionic acid silvex produce much less pronounced formative effects and less damage at the same dosage as 2,4–D.

Most of the complaints have been caused by drift of 2,4–D onto cotton, but there has been injury to truck crops, vegetable gardens, fruit trees, and even ornamentals. In a few cases heads of rice failed to fill out properly because of 2,4–D. Circumstantial evidence points to serious reductions in stand due to drift onto newly sprouted rice in Louisiana.

Beyond a certain point, educational programs have had little effect in eliminating hazards in the use of 2,4–D. For this reason, a number of states have found it desirable to enact regulatory measures. These regulatory laws are similar in many respects. Because of the complexity of the problem, the laws are, to a large degree, enabling acts which authorize the Commissioner of Agriculture or equivalent, after hearing, to adopt such rules and regulations as may be appropriate.

Laws in Louisiana and Texas provide for zoning according to type of agriculture and season. About half the area of Texas is exempt from the law. All states have restrictions on distance from susceptible crops by application and ferrying. Use of dust and volatile ester formulations of 2,4–D is restricted. Report of application is required. Provision is made for examination of operators and inspection of equipment. Licenses are required in these states. Provision is made for establishment of financial responsibility of operators, but in Mississippi and Arkansas is limited to non-resident operators. In Mississippi the law applies only to aerial operators. Dealer permits and records of sales are required in Arkansas and Texas.

Essentially similar requirements for cut-offs on nozzles and tanks exist in all states. In Mississippi and Arkansas no spraying is permitted when wind velocity exceeds 5 miles per hour. In Louisiana and Texas spraying may be done up to wind velocities of 10 miles per hour. In Mississippi and Arkansas, aircraft must not spray when more than 10 feet from the ground, Texas allows up to 15 feet. Notice of intent to spray must be posted in Arkansas. In Texas, a permit must be obtained and a 10 cent per acre fee paid. Texas also provides for actual supervision of operations under certain conditions.

In some states, the law and regulations have led to a reduction in number of complaints, in others there is yet room for improvement. In 1957, complaints in Louisiana decreased from an average of 150 per year to 24. Part of this has been due to weather and crop conditions rather than enforcement. In Texas, there has been a remarkable decrease. These complaints have dropped from over

1000 in 1952 to only 3 in 1957. In view of the similarity of the laws and regulations in the various states it would seem that differences in extent to which damage claims have been reduced is due to degree of enforcement.

Because of the extreme hazard of 2,4–D to cotton and other broadleaved crops, a number of states have found it necessary to regulate its use. Laws and regulations of this kind have been in effect for sufficient time to permit evaluation. The following regulatory requirements are listed in order of importance.

1. Establishment of financial responsibility by custom operators.
2. Restrictions on wind velocity and direction at time of application.
3. Prohibition of dust and volatile ester formulations.
4. Ensuring competency of operators.
5. Inspection of equipment.
6. Requirement of permits before application and reports after application.
7. Complete control of sale and movement of 2,4–D from manufacturer to user.

Where the land use pattern is complex all of the above would be necessary to minimize damage to susceptible crops. In less complex situations regulatory requirements need not be so comprehensive. It should be emphasized that mere promulgation of regulations offers nothing. Regulations must be actively enforced and in order to do this ample funds must be available to employ proper personnel. If regulations are to be completely enforced a rather large field force will be necessary. In some cases several men would be needed for a single country. Much of the success in reducing 2,4–D damage in Texas has been due to effective enforcement. Apparently the permit fee provides sufficient funds for employment of adequate enforcement personnel.

Workers in the field of weed control have necessarily concentrated on the end result, elimination of weeds. Less emphasis has been placed on reducing possibility of damage to crops other than the one being treated. While the hazards have been recognized and publicized, relatively little work has been directed to means of reducing or preventing drift. The so-called "invert" emulsions offer some hope in this area but the need for extensive work on drift prevention cannot be too strongly emphasized. As new and more potent herbicides appear, new hazards will arise. It is not too early to begin the search for means of forestalling undesirable effects.

News and Notes

John Ahrens will be devoting part time research to control of weeds in stalk-out tobacco and nursery stock at the Windsor station of the Connecticut Agr. Exp. Station. Ahrens received his Ph.D. degree from Iowa State College in 1957.

Donald T. Lillie was appointed by the Crops Research Division, ARS, USDA, to conduct research on the control of chaparral. The work is cooperative with the U. S. Forest Service and will have headquarters at Arizona State College, Tempe, Arizona. Lillie was awarded a Ph.D. degree by Rutgers University in June, 1958.

Members of the sub-committees of the Committee on Agricultural Pests, Agricultural Board, National Research Council met in Washington, D. C., on October 20 and 21, 1958, to develop methods of determining more precisely the losses incurred by agricultural pests. The Sub-committee on Weeds consisted of W. B. Ennis, Jr., W. A. Harvey, G. C. Klingman and R. L. Warden with O. C. Lee as chairman. The goal of the Sub-committee on Weeds is to encourage various organizations in government, industry and education to secure factual data on losses due to weeds in all aspects of our economy, both agricultural and non-agricultural. Detailed data of this type are not now available. They are needed to determine the magnitude of weed losses now prevalent and to guide the work of research workers into fields where losses are especially serious. The Sub-committee will develop guides for use by workers in determining weed losses and will encourage all those interested in weed control to assemble and publish data as it becomes available.

Lowell Jordon has accepted an appointment with the California Agricultural Experiment Station to work on weed control in citrus crops at the Riverside Station. He was formerly a member of the staff of Southern Illinois University, Carbondale, Illinois.

Errata

In Issue 4, Vol. 6, the seventh line on page 462 reads "disease as measured by the percentage of seed planted" and should read "disease as measured by the percentage *emergence* of seed planted."

In Issue 4, Vol. 6, the forty-ninth line on page 462 reads "observation at least 12 days after planting" and should read "observation at least *21* days after planting."

Sustaining Members

American Chemical Paint Co., Ambler, Pennsylvania
American Smelting & Refining Co., Central Research Laboratories, South Plainfield, New Jersey
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Chipman Chemical Company, Bound Brook, New Jersey
Crag Agricultural Chemicals Division, Union Carbide Chemicals Co., White Plains, New York
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Diamond Alkali Company, Cleveland, Ohio
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Monsanto Chemical Company, St. Louis, Missouri
National Aluminate Corp., Chicago, Ill.
O. M. Scott & Sons Company, Marysville, Ohio
Reade Manufacturing Company, Inc., Jersey City, New Jersey
Spraying Systems Company, Bellwood, Illinois
Stauffer Chemical Company, New York, New York
Swift and Company (Plant Food Division), Chicago, Illinois
Thompson-Hayward Chemical Company, Kansas City, Missouri
United States Borax and Chemical Corp., Los Angeles, California

BIBLIOGRAPHY OF WEED INVESTIGATIONS
for
April, May, and June, 1958

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Prepared By
UNITED STATES DEPARTMENT OF AGRICULTURE
Agricultural Research Service
Crops Research Division

This bibliography of current literature on weeds and their control is issued as a service to those engaged in weed research in the United States and other countries. In issuing this bibliography the Crops Research Division, Agricultural Research Service, U.S.D.A. does not assume responsibility for the subject matter cited.

Beltsville, Maryland

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Suggestions for Contributors to WEEDS

Manuscipts dealing with all aspects of weed control, regulatory, educational and research, are accepted for publication in WEEDS. Manuscripts should have more than purely local interest. The material described should be more conclusive than progress reports. Articles must be original material previously unpublished elsewhere. Prior publication in brief abstract form is permitted. After review, each manuscript will be accepted for publication upon recommendation of the Editorial Board. The author has the opportunity to make revisions after the review is completed and before publication. Refer to a recent issue of WEEDS to determine details of style to be used.

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Use as short a title as practical. Following the title give the authors name(s). It is desirable to divide the manuscript into sections with headings such as Introduction, Methods and Materials, Results, Discussion, Summary and Literature Cited. Avoid underscoring headings, words or phrases unless you wish them to be printed in italics.

Measurements such as time, weight and degrees should be in arabic numerals regardless of the number of digits in the number. Where the figure is not one of measurement, figures below 10 should be spelled out except when one figure in a series has two digits in which case all should be in arabic.

All chemicals mentioned should be described fully the first time used. Nomenclature, abbreviations and definitions should follow those presented in the Terminology Committee Report, WSA, published in WEEDS 6:71–76, January, 1958.

Footnotes. Use footnotes sparingly for items that cannot be included conveniently in the text. The place where the study was done and the address of the author(s) should be given as footnotes. Number footnotes to the text consecutively throughout the manuscript with superscript arabic numerals. Designate footnotes to the tables with superscript lower case letters.

Figures. Experimental data may be presented in graphic or tabular form. However, figures should not be used if they merely illustrate material presented in the text or in tables. Prepare illustrations with approximately the same proportions as a printed page, 4⅜ x 7 inches, or some fraction of a page. Photographs should be clear glossy prints and should be trimmed of unessential portions.

Graphs and drawings should be inked with heavy black lines to ensure clarity after reduction in size. Hand lettering should be large and made with a lettering guide. Typing is not acceptable. Place the author's name and figure number on the back of each one submitted. Type the legend for each figure on a separate sheet. Figures should be numbered consecutively in arabic numerals.

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